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PHYSICAL-CHEMICAL TREATMENT AND DISINFECTION OF
STORMWATER. 1982.

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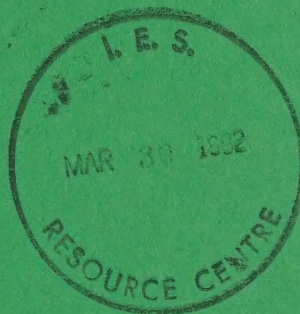
PHYSICAL-CHEMICAL TREATMENT

DISINFECTION OF STORMWATER

RESEARCH REPORT No. 88

MARCH 1982

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Deputy Minister

PHYSICAL-CHEMICAL TREATMENT AND

DISINFECTION OF STORMWATER

RESEARCH REPORT # 88

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MARCH 1982



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SUMMARY

Urban land runoff from a 22.7 hectare essentially residential watershed in East York, Metropolitan Toronto, Ontario, was studied during May to October, 1977 and April to July, 1978. The study program comprised characterization of hydrologic events, stormwater quality, and the application of simple treatment methods including coagulation/sedimentation and disinfection at the bench and pilot scale level.

Hydrologic parameters such as rainfall intensity, runoff, storm sewer flow rates, total runoff volumes per event, antecedent dry periods and runoff coefficients varied widely.

Pollutant concentrations in the stormwater also varied widely, particularly for SS and COD.

Typical average percentage pollutant removals by natural or chemically assisted settling for 13, 1977 storm events were as follows:

	<u>POLLUTANT REMOVAL - %</u>	
	<u>Natural Settling</u>	<u>Chem. Assist. Settling</u>
SS	88	95
BOD ₅	36	68
COD	57	62
Total-P	47	79

For chemically assisted settling, alum was established as the preferred flocculant at an average dosage of 30 mg/L followed by at least two hours of quiescent settling. For natural settling, no relationship was established between settling time and pollutant removal. It is felt, however, that ten hours of quiescent settling, on the average, should remove the bulk of the settleable matter.

The sums of potential pollutant mass loadings with and without treatment for the 13, 1977 storm events were estimated as follows:

POLLUTANT MASS LOAD - kg/ha

	<u>SS</u>	<u>BOD₅</u>	<u>COD</u>	<u>Total-P</u>
No Treatment	316	13.5	179	0.2
Settling Only	40	8.6	77	0.1
Chem. Assist. Settling	16	4.3	68	0.04

Indicator bacterial densities in raw stormwater did not vary significantly between events. Observed G.M. fecal and total coliform densities were 9.0×10^3 and 7.5×10^5 , respectively. Natural settling (9 to 50 hours) did not reduce bacteria density levels. Chemically assisted settling produced moderate and erratic reductions. Disinfection with NaOCl at a dosage of 5.0 mg/L available chlorine reduced indicator bacterial densities to well below MOE objectives; typically to less than 10 counts/100 ml for fecal coliforms. No bacterial regrowth was observed for up to 48 hours. Chlorine demand varied widely.

CONCLUSIONS

Conclusions and findings of this report are based on the information obtained from this catchment area, and do not necessarily represent other urban areas.

Stormwater Characteristics

1. Pollutant concentrations within a precipitation event varied with the prevailing rainfall intensity.
2. Total phosphorus and nitrogen (TKN) concentrations in the runoff were consistently low and varied little. Average values were 0.5 and 2.2 mg/L, respectively.
3. Of eight trace metals analyzed, only iron concentrations were in violation of the MOE model industrial waste bylaw.
4. Geometric mean, fecal and total coliform densities in stormwater were 9.0×10^3 and 7.5×10^5 , respectively.
5. The average ratio BOD_{20}/BOD_5 of 3.7 shows that only about one-quarter of the potential BOD exerts a short-term oxygen demand. It also suggests a potential long-term effect of the substrate in stormwater upon the receiving water.

Stormwater Treatment

6. Treatment of stormwater by natural settling only (9 to 50 hours) achieved substantial pollutant reductions as indicated below. Natural settling did not affect indicator bacterial removals.

	<u>% Pollutant Removal Settling Only</u>
SS	88
BOD ₅	36
COD	57
Total-P	47
Turbidity	49

7. Treatment by chemical flocculation with an average dosage of 30 mg/L alum and followed by two hours of quiescent settling attained excellent pollutant reductions as indicated below. Chemically assisted settling produced moderate and erratic indicator bacterial reductions.

	<u>% Pollutant Removal Alum Floc</u>
SS	95
BOD ₅	68
COD	62
Total-P	79
Turbidity	88

8. Residual effluent concentrations following settling only, or chemically assisted settling, are within the presently attained quality of primary and secondary WPCP effluents. Chemical flocculation produces an effluent quality similar to that of MOE secondary WPCP.
9. Variable trends in natural settling characteristics from one storm event to another are essentially eliminated by chemically assisted settling.
10. It is felt that no additional substantial pollutant removals occur beyond a ten hour settling time.
11. Removal efficiency for either natural or chemically assisted settling did not vary with suspended solids concentrations above 200 mg/L.
12. Natural settling alone may, with the exception of bacterial removal, provide adequate treatment for stormwater. Site specific evaluation will be necessary.
13. Chemically assisted settling achieved consistently higher pollutant removals for equal settling times when compared to natural settling.

14. The sums of potential pollutant mass discharges based upon observed runoff events for which both quality and hydrological data were available were estimated as follows with and without treatment:

		<u>POLLUTANT MASS - kg/ha</u>			
		<u>SS</u>	<u>BOD₅</u>	<u>COD</u>	<u>Total-P</u>
No Treatment	kg/ha	316	13.5	179	0.20
Settling Only	kg/ha	40	8.6	77	0.10
Alum Floc	kg/ha	16	4.3	68	0.04

15. Storm events having a runoff volume in excess of 800 m³ (73% of total observed runoff volume) contributed 92%, 88% and 86% of the SS, BOD₅ and COD pollutant mass loads, respectively.
16. Disinfection with NaOCl, at a dosage of 5.0 mg/L as total available chlorine, reduced in all cases total and fecal coliform to below 100 counts/100 ml and 10 counts/100 ml, respectively.
17. No regrowth of indicator bacteria was observed within 48 hours following disinfection with NaOCl.

1.0 INTRODUCTION

Interest in the control of pollution resulting from urban drainage has developed in Ontario. The background leading to the need for the present project is described in this section.

Historically, many municipalities designed and constructed combined sewer systems for the transportation of surface runoff, sanitary sewerage and industrial wastes from developed areas. In other municipalities, separate sanitary and storm sewer systems were constructed from the outset.

Beginning in the late 1940's most new sewer systems were separated systems. In addition, at least primary treatment for combined sanitary and industrial sewage was included for most municipalities.

These two trends have continued to the present. Construction of new combined sewers is virtually non-existent today in Ontario and most municipalities provide secondary treatment.

Beginning in the 1950's, many municipalities with combined sewers embarked upon sewer separation programs. Separation was adopted primarily as a means of alleviating the associated flooding problems in sewage conveyance. Sewer reconstruction for redevelopment, maintenance, etc. also resulted in the replacement of combined sewers by separate storm and sanitary sewers. Thus, the number of separated sewers is steadily increasing in the Province.

It has long been recognized that the urban runoff entering a storm sewer also carried surface pollutants to the receiving water. The annual and shock loads of pollutants reaching a given receiving body from stormwater become relatively more significant each time a higher standard of sanitary sewage treatment is achieved for the same area. With the application of advanced treatment methods (phosphorus removal, nitrification and final effluent filtration) for

sanitary wastes, the loadings from stormwater may become critical for maintaining water quality at certain locations.

Comparatively few studies have been conducted on the treatment of stormwater runoff. The Urban Drainage Sub-Committee of the Canada-Ontario Agreement, recognizing the scarcity of published data, decided to sponsor this study.

A review of the literature indicated wide ranging quality characteristics of stormwater from many locations inside and outside Ontario (1). Based on this information, and also because of the inherent variability of stormwater runoff events, it was decided to concentrate the study on Physical-Chemical Treatment of stormwater followed by Disinfection.

2.0 OBJECTIVES

The primary objective of this study was to investigate the potential for pollutant removals from residential stormwater by natural settling, chemically assisted settling and terminal disinfection.

A secondary study objective was the characterization of hydrological events, runoff volumes and stormwater pollutional quality. These data were used to estimate pollutant loads and to evaluate treatment techniques.

3.0 SCOPE OF THE STUDY

Stormwater monitoring, conducted during summer and fall seasons, included the collection of rainfall data, storm sewer flow rates and stormwater and debris samples.

Physical-chemical treatment studies of stormwater, including disinfection, were undertaken at the bench and/or pilot scale level. Treatment techniques comprised natural and chemically assisted settling resembling impoundment. Bench scale studies were initially undertaken to approximate for subsequent pilot scale treatment studies. The effectiveness of chemical flocculation and disinfection were established on remixed (initially settled) stormwater. Treatment efficiency by natural settling was based on freshly collected stormwater. Potential mass pollutant loads, with and without treatment, from the residential catchment were estimated on the basis of this study.

Mainly due to the intermittent runoff characteristics of stormwater, biological treatment was not considered. The expected minimal quantities of sludge both from natural and chemically assisted settling did not warrant study. Due to the unpredictable occurrence of storm events, the effect of settling time on treatment efficiency by natural settling was not systematically established. For the same reason, and also due to the time required for staff to arrive at the study site following a storm event, settling times of less than 9 hours were not evaluated.

Catchment characteristics were determined during a previous study (1).

4.0 TECHNICAL BACKGROUND

Stormwater runoff has been recognized as a potentially significant pollutant source. The pollutant discharges normally originate from the washoff by surface runoff of roads, parking lots, driveways, roofs, lawns, etc. They are intermittent in nature.

The prevailing land use of the respective drainage area may significantly affect the type and quantity of pollutants observed in the runoff. In addition, stormwater may also contain considerable quantities of gross particulate matter (debris).

Stormwater discharged from typical Ontario catchment areas has been characterized as shown in Table 1 (2). These results illustrate the widely varying quantities of pollutant matter found in urban stormwater.

Table 2 compares the relative magnitudes of pollutant concentrations in raw sewage, treated sewage, combined sewer overflows and stormwater runoff according to the Canada/Ontario Agreement Research Report No. 94 and the Ontario Ministry of the Environment guidelines for the design of primary, secondary and tertiary water pollution control plants (4).

The potential significance of stormwater discharges in Ontario has been investigated by the APWA by using methods and procedures developed for similar studies in the United States (5). The study generally indicated that for stormwater discharge, annual loadings are not as critical as shock loadings occurring with each major storm event.

The study suggested the following means for pollutant reduction:

- 1) Attack pollution at the source by removing dirt and dust more thoroughly from impervious areas and/or use modified catchbasin sumps which could act as sediment collectors requiring frequent cleaning.

TABLE 1 (2)
STORMWATER QUALITY DATA COLLECTED FROM OTHER STUDIES IN ONTARIO

PARAMETERS	BOD ₅ mg/L	COD mg/L	SOLIDS		Cl mg/L	Pb mg/L	NITROGEN			PHOSPHORUS		PHENOLS ppb	COLIFORMS	
			TOTAL mg/L	SUSP. mg/L			Kjel. mg/L	NO ₂ mg/L	NO ₃ mg/L	TOTAL mg/L	SOL. mg/L		TOTAL MPN/100 ml	FECAL MPN/100 ml
BRUCEWOOD range of concentration range of means	min. max.	<10 920	300 1200	10 1000	2 10,300	0.02 1.80	0.3 19.0	<0.02 0.26	<0.2 4.7	0.04 1.60	<0.02 0.68	0 43	100 110,000	10 19,000
	min. max.	66.0 125.5		81 149	354 976	0.32 0.54	2.2 4.0		1.4 2.3	0.22 0.43	0.06 0.11	4.3 12		
GUELPH-NORTH range of concentration range of means	min. max.	18 320	72 2300	10 1090	1 68		0.4 5.3	0.01 0.22	<0.2 4.6	0.04 1.6	0.004 0.072		< 10,000 830,000	< 1,000 71,000
	min. max.	60 89	364 564	87 159	22 67		2 3	0.06 0.10	0.59 1.05	0.25 0.35	0.020 0.028			
BROADVIEW range of concentration range of means	min. max.	48 490		400	84	0.46	7.5	0.14	2.1	1.00		7		
	min. max.	9.9 23.0		50.8 232.4	19.8 71.0	0.32 0.85	1.3 3.6	0.085 0.090		0.28 0.58		1.6 5.7		
MALVERN range of concentration range of means	min. max.	5.3 312		2.8 681						0.01 1.50				
	min. max.	22.0 119.6		6.8 194.8						0.01 0.51				
WINDSOR-A range of concentration range of means	min. max.	78.4	23 1230		4 1585			0.001 0.570	4.7				200 1,200,000	100 20,000
	min. max.	14.0 26.8	111 467		29 122			0.045 0.054	1.05 1.37					

TABLE 2

COMPOSITION OF SEWAGE AND STORMWATER
C/OA Report No. 94

	BOD ₅ mg/L	SS mg/L	TOTAL-N mg/L	TOTAL-P mg/L	COLIFORMS per 100 ml	FECAL COLIFORMS per 100 ml
Raw Sewage	165	225	30	6.5	1×10^8	1×10^7
Treated Sewage -Primary	50	50	22	1.0	1×10^4	1×10^6
-Secondary	17	23	18	1.0	1×10^4	1×10^3
Combined Sewer Overflow	41	190	8.3	1.4	1×10^7	1×10^6
Stormwater Runoff	14	170	3.5	0.35	2×10^4	5×10^3

*Ministry of the Environment Design Objectives (with P removal) (4)

Primary	90	30		1.0		
Secondary	15	15		1.0		
Tertiary	10	5		0.3		

* Treatment Requirements are Site Specific

- 2) The application of well established, suitable treatment processes just prior to discharge to the receiving water. This type of treatment would likely include some form of storage.
- 3) Improved planning of sewer systems and urban developments to include ground infiltration (recharge ponds), where possible, to reduce or eliminate runoff to the storm sewer or receiving water.

Recent developments in stormwater management or treatment have led to the development of artificial lakes with multi-purpose use. Some the the latter have been successfully integrated with new developments in Mississauga, Windsor, Ottawa, Winnipeg and Midland.

As the result of the intermittent nature of urban runoff and its widely varying quality, conventional treatment of stormwater presents special problems. A number of treatment processes, such as lagooning, micro-straining, fine mesh screening, high rate filtration, physical-chemical treatments, dissolved air flotation and modified biological processes have been extensively studied and documented through EPA grants in the United States (6,7,8,9,10).

Conventional sedimentation using ponds or clarifiers, with or without chemical aids, is presently the preferred approach to stormwater treatment (6). Stormwater disinfection is currently not widely practiced. Results from a full scale stormwater disinfection project in New Orleans where NaOCl was successfully used as the disinfectant is well documented (11).

Although many treatment processes have been evaluated, no particular type of treatment is universally applicable for runoff from separated systems.

5.0 DESCRIPTION OF THE STUDY AREA

5.1 Site Location and Selection

The Barrington catchment area located in East York was selected for the study over a number of other possible sites within Metropolitan Toronto. Considerable background information relating to the catchment area, the storm sewer system, and runoff quantity and quality was already available. This information was obtained in a previous study (1) carried out by G. Mills, the then Director of Engineering for the Borough of East York. In addition, the storm sewer system has no known sanitary connections which are often encountered in older areas. The receptive attitudes of the Municipality and its staff in expediting approval to work in this location, together with the relative proximity to the Ministry of the Environment Central Laboratory and Section Office, also affected the selection of this site.

The drainage area is situated primarily in the Borough of East York, and is commonly referred to as the Barrington storm sewer area. The relative location of the drainage area within Metropolitan Toronto is indicated in Figure 1. A detailed outline of the drainage area is presented in Figure 2. The small drainage area consists of about nine primarily residential city blocks.

5.2 Land Use

The Barrington drainage area consists of single family residential houses except for some small retail stores. With few exceptions, the houses in the area are between 50 to 70 years old.

The characteristics of the drainage area, comprising 22.7 hectares (56 acres) are detailed in Table 3.

5.3 Climate

Mean daily summer/fall (May to October) temperatures for the Toronto area, from 1941 to 1970, range from 11°C to 21°C (52°F to 71°F). Mean monthly rainfall for this period ranges from 61 to 81 mm (2.4 to 3.18 inches).

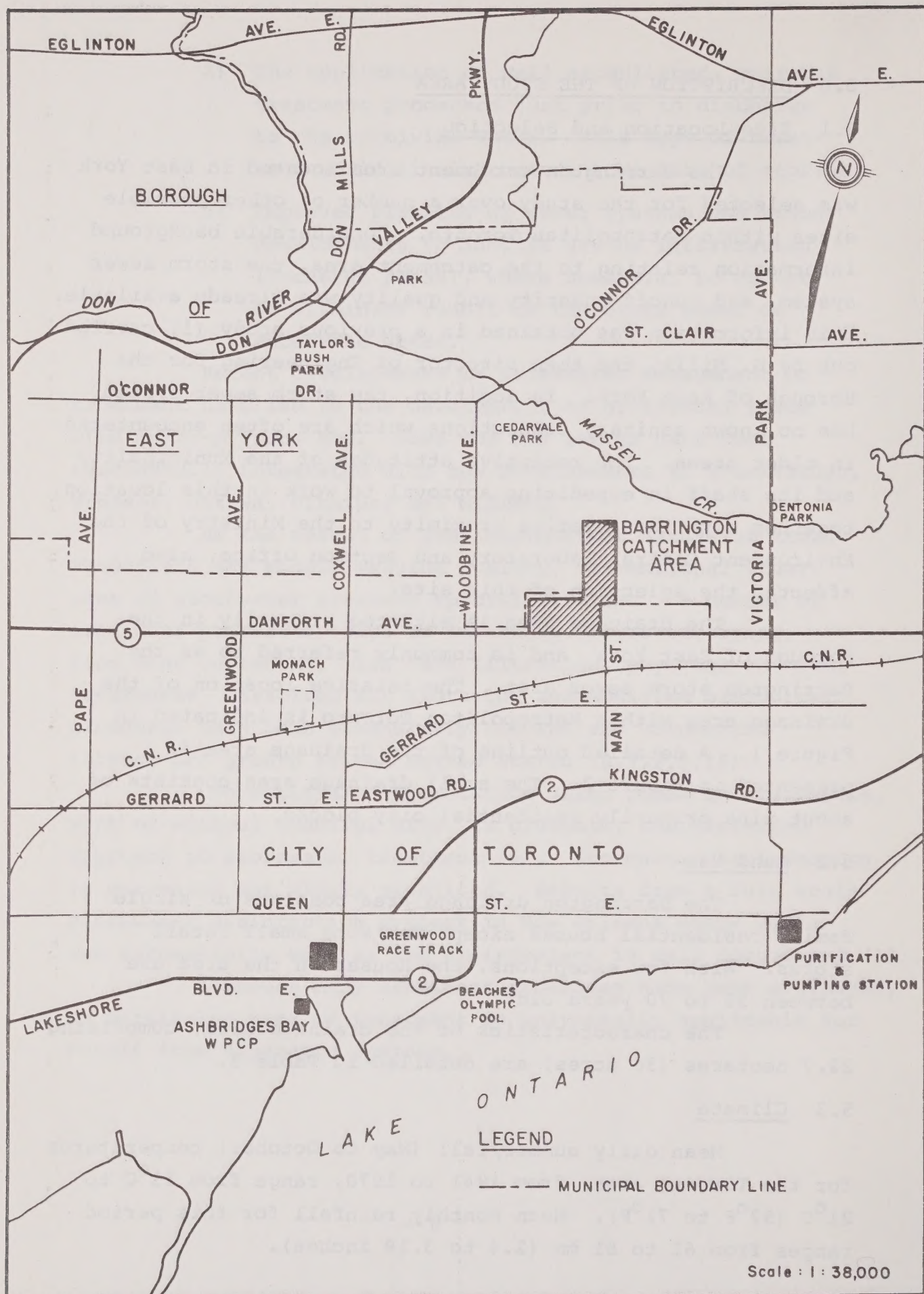


FIGURE 1: BARRINGTON CATCHMENT LOCATION WITHIN METROPOLITAN TORONTO

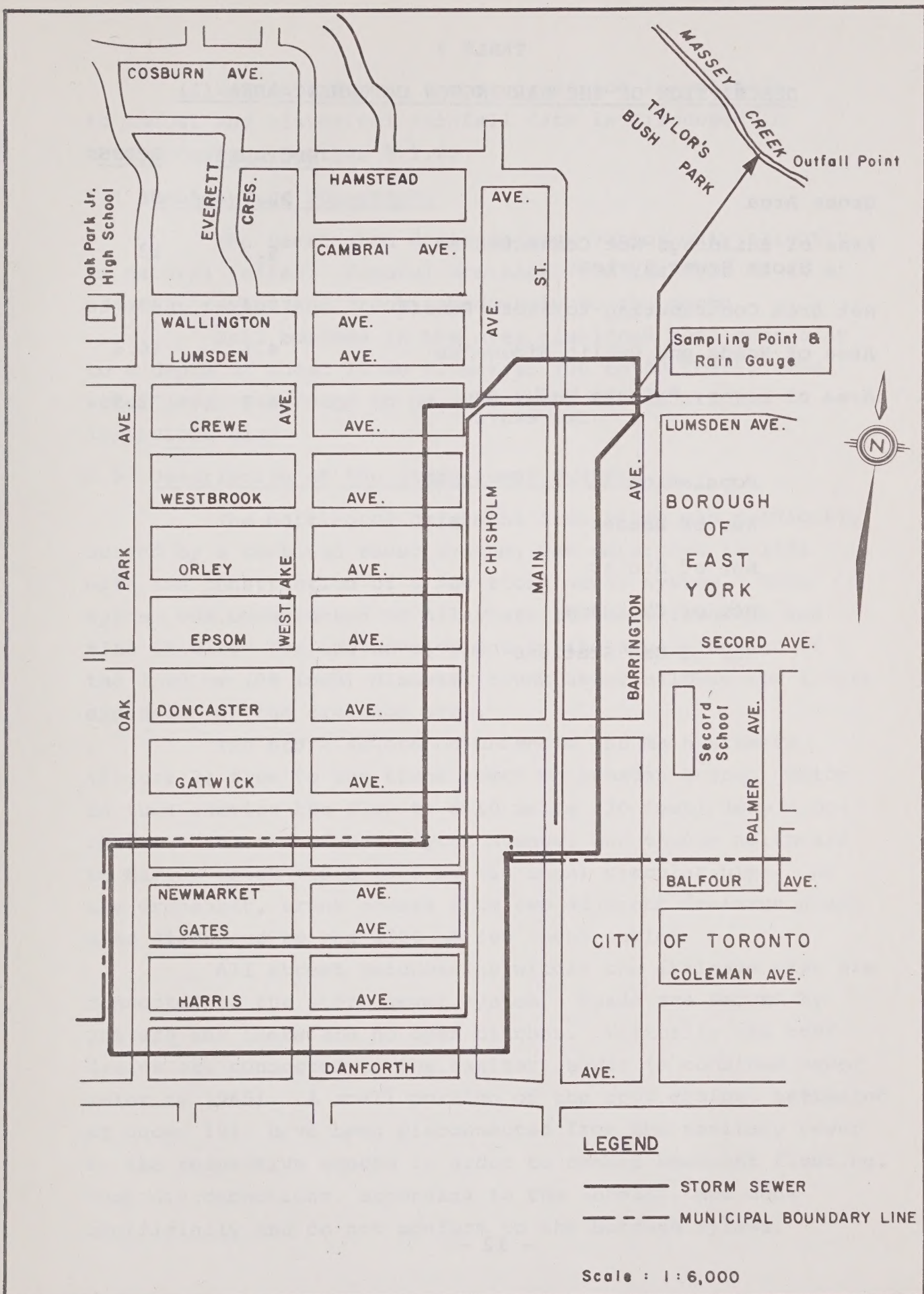


FIGURE 2 : BARRINGTON CATCHMENT AREA

TABLE 3

DESCRIPTION OF THE BARRINGTON CATCHMENT AREA (1)

	<u>HECTARES</u>	<u>ACRES</u>
Gross Area	22.7	56
Area of Buildings Not Connected to Storm Sewer System	5.3	13
Net Area Contributing to Storm Runoff	17.4	43
Area of Roads and Public Sidewalks	4.1	10.1
Area of Lawns, Private Walks and Driveways	13.3	32.9

Population 2550

No. of Houses 511

No. of Stores 7

No. of Churches 2

No. of Gas Stations 1

Rainfall during the study period in relation to annual and historical rainfall data is discussed in more detail in Section 7.1.2.

5.4 Geology and Topography

The Barrington drainage area varies only slightly in natural relief. Natural drainage from the area is to an adjacent ravine and creek immediately to the north.

Soil borings in the area disclosed sand over clay to a depth of about 10 to 12 metres (30 to 40 feet). The water level was found to be just above the underlying impervious clay.

5.5 Description of the Storm Sewer System

The Barrington catchment area which was previously served by a combined sewer system, was separated in 1965 with the construction of a new storm sewer system. This system was constructed to alleviate basement flooding and also to allow for new development in the area. Design of the 2500 mm (96 inch) diameter trunk sewer allowed for future expansion of the drainage area.

The storm sewers on Chisholm and Main Streets (Figure 2) flow to the trunk sewer on Lumsden Avenue, which in turn carries the flow to a 10 metre (30 feet) deep dropshaft at the end of Barrington Avenue, and thence northward to Massey Creek via a 1500 mm (60 inch) circular pipe. At the dropshaft, trunk sewers from two adjacent drainage areas also discharge to the 1500 mm (60 inch) outlet.

All street catchbasins within the drainage area are connected to the storm sewer system. Roads are served by gutters and there are no open ditches. Virtually all roof drains are connected to the sanitary sewer (a combined sewer prior to 1965). A small portion of the roof drains, estimated at under 10%, have been disconnected from the sanitary sewer by the respective owners in order to combat basement flooding. Such disconnections, according to the Borough, are done unofficially and do not conform to the Borough Bylaws.

However, no action has been taken by the Borough provided disconnected roof drainage does not adversely affect adjoining properties. Drainage from disconnected roof leaders is to the storm sewer directly or indirectly across lawns. No known interconnections exist between the old sanitary system (originally combined) and the new storm sewer system. Weeping tiles drain to the sanitary system.

5.6 Description of the Receiving Water

The storm sewer for the Barrington and adjacent drainage areas discharges to Massey Creek, about 300 metres (1000 feet) north of the dropshaft. Massey Creek passes through Metropolitan Toronto Parkland (Taylor's Bush Park) prior to discharging to the Don River, which in turn flows to Lake Ontario. The distance from the storm sewer outfall to the Don River is about 3 km (1.75 miles). No flow data is available for Massey Creek, which originates about 8 km (5 miles) north of the storm sewer outfall. In the vicinity of the Barrington storm sewer outfall, a number of other storm sewer outlets discharge into Massey Creek, mainly providing drainage from highrise buildings along the creek as well as natural drainage to the ravine.

5.7 Municipal Practices

Streets are normally swept once a week by a pick-up sweeper when there is no snow or ice present, i.e. during April to November. On rainy days, road gutters are cleaned manually in the vicinity of the catchbasins. No information is available on the amount of litter and debris picked up or removed from within the study area.

The municipality does not have a regular program of storm sewer cleaning. First priority is the day-to-day sewer problems which may occur. Secondly, attempts are made on a regular basis to maintain sewers known to have trouble spots. Thirdly, trouble-free sewers up to 525 mm (21 inches) in diameter are cleaned. No information is available on how often trouble-free sewers are cleaned but it does not appear to be as frequent as once per year.

Catchbasins are cleaned once per year by means of a vacuum hose. Catchbasin sludge is collected in a tank truck but during the study period, it was noted that supernatant from the tank is returned to the storm sewer.

6.0 DESCRIPTION OF EXPERIMENTAL FACILITIES AND TESTING TECHNIQUES

6.1 General Discussion

The on-site, fully automated, monitoring equipment included instrumentation for the measurement of precipitation, storm sewer flow rates and the collection of stormwater samples for both characterization and treatment studies. To minimize vandalism, all the aboveground installed equipment was set up within a fenced compound and/or an electronically protected shed.

Figure 3 gives a schematic of the installed above and below ground facilities. The aboveground instrumentation set up within the shed, consisted of flow measurement instrumentation, sample pump controls and the raingauge recorder. The tipping bucket of the raingauge was located on the roof of this shed. The compound also contained a sequential sampler and three storage/treatment tanks.

Below ground, a wet well with sample pump was located on a grated platform within the dropshaft. A compound slot weir provided with two bubbler lines was installed upstream of the dropshaft to facilitate independent measurements of low and high flow rates.

6.2 Description of Dropshaft

A schematic of the dropshaft with installed equipment is shown in Figure 4. The wooden platform, especially constructed for this study was well supported against the bottom of the main dropshaft. To prevent sewer flooding, sufficient open space was allowed within the platform.

Apart from the storm sewer designated as "A", which was studied, two other storm sewers designated "B" and "C", also discharge into the main dropshaft and are, for reference purposes, included in Figure 4. The relative discharge locations of the three storm sewers "A", "B" and "C" to the main dropshaft are indicated in the side and top views of Figure 4. Sewers "A" and "C" are at the same elevation, while sewer "B" is 3 m above sewers "A" and "C".

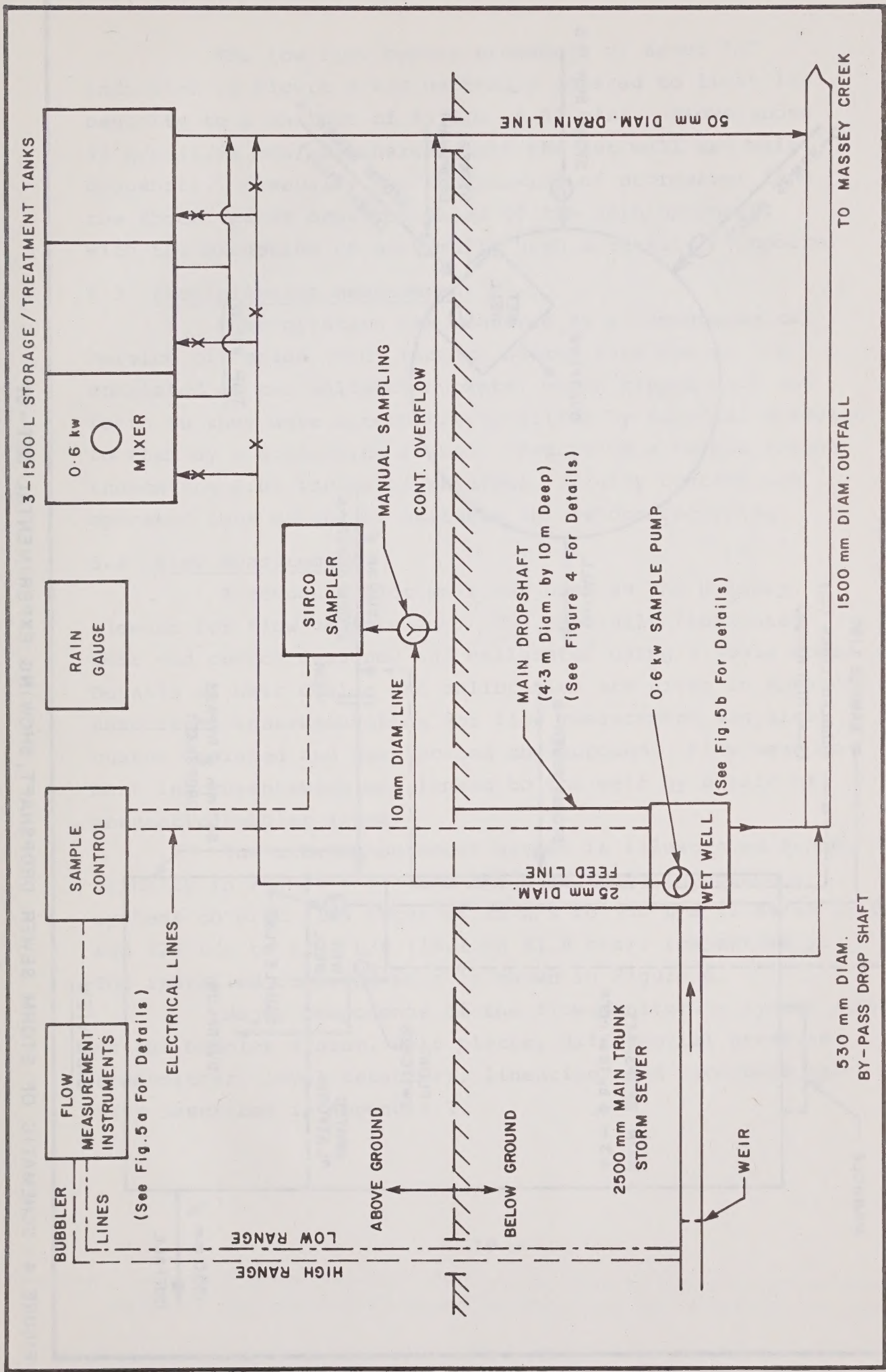


FIGURE 3 : SCHEMATIC LAYOUT OF MONITORING EQUIPMENT AND PILOT TREATMENT UNITS.

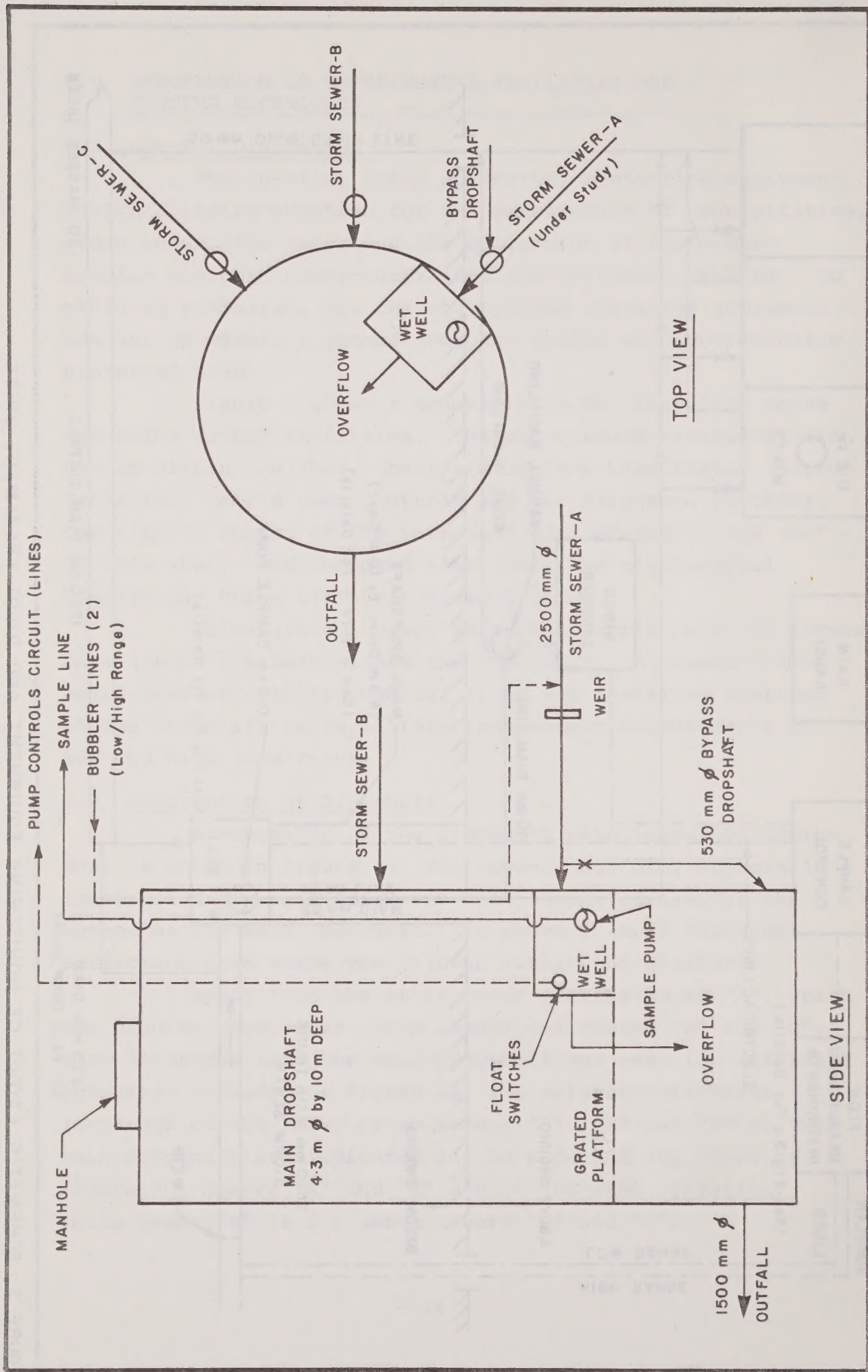


FIGURE 4 : SCHEMATIC OF STORM SEWER DROPSHAFT, SHOWING EXPERIMENTAL SET -UP.

The low flow bypass dropshaft of sewer "A" indicated in Figure 4 was partially covered to limit its capacity to a maximum of 45 L/s (1.61 cfs). Flows above 45 L/s (1.61 cfs) discharged into the wet well and main dropshaft. Generally, no intermixing of stormwater from the three sewers occurred ahead of the main dropshaft with the exception of abnormally high intensity downpours.

6.3 Precipitation Measurement

Precipitation was measured by a Meteorological Service of Canada (MSC) tipping bucket rain gauge. It consisted of two balanced buckets, which tipped back and forth as they were alternatively filled by rainfall directed to them by a collecting tunnel. Everytime a bucket tipped indicating 0.01 inches of rainfall, a relay contact was operated thus making it suitable for remote recording.

6.4 Flow Measurement

A compound slot weir was used as the primary element for flow measurement. The specially fabricated weir was custom designed and calibrated using a scale model. Details of weir design and calibration are given in Appendix 1. Associated instrumentation for flow measurement was also custom designed and was located aboveground. Flow measurement instrumentation was linked to the weir by a pair of pneumatic bubbler lines.

The flow measurement system is illustrated schematically in Figure 5-A. Low and high range independent systems covered flow rates of 45 L/s to 750 L/s (1.61 to 26.8 cfs) and 424 L/s to 2292 L/s (15.1 to 81.8 cfs), respectively. The installed compound weir is shown in Figure 6.

Major components of the flow monitoring system such as the bubbler system, weir plates, differential pressure transmitter (level detector), linearizer and recorders are also described in Appendix 1.

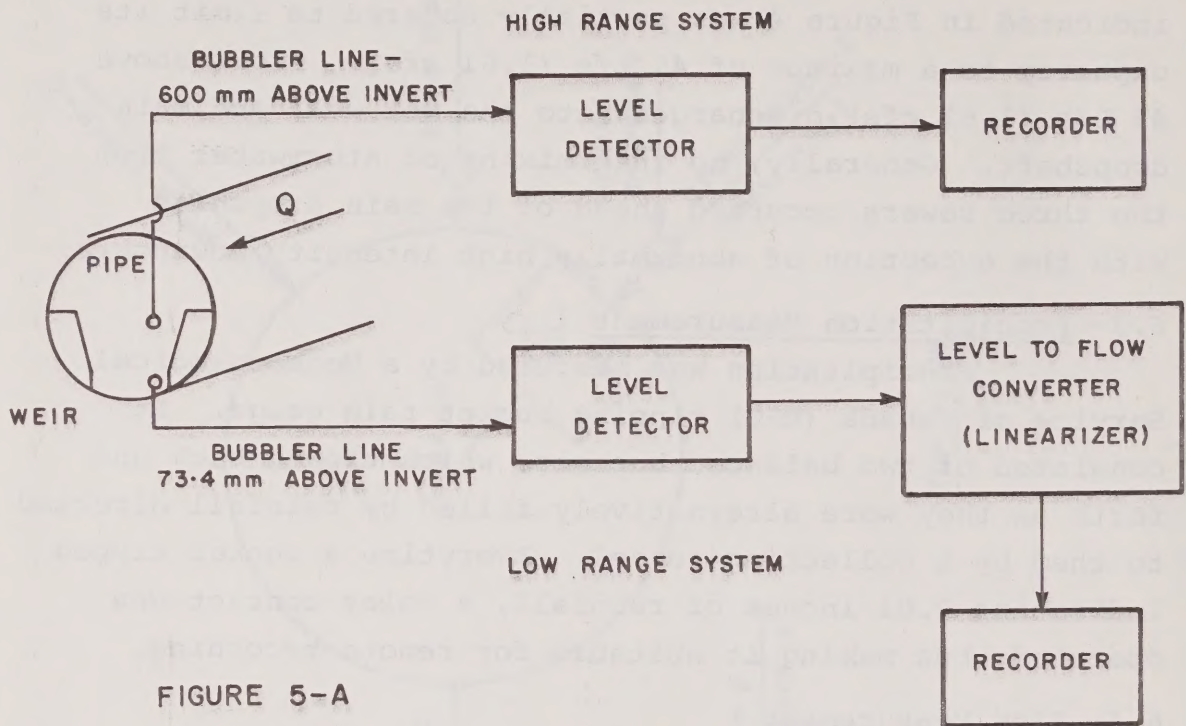


FIGURE 5-A

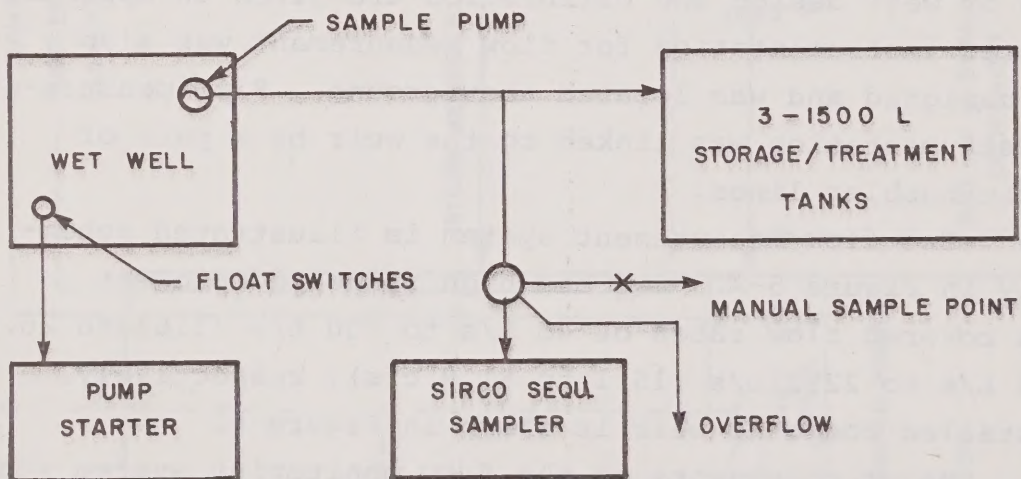


FIGURE 5-B

FIGURE 5 : SCHEMATIC OF FLOW MEASUREMENT AND SAMPLING SYSTEMS.

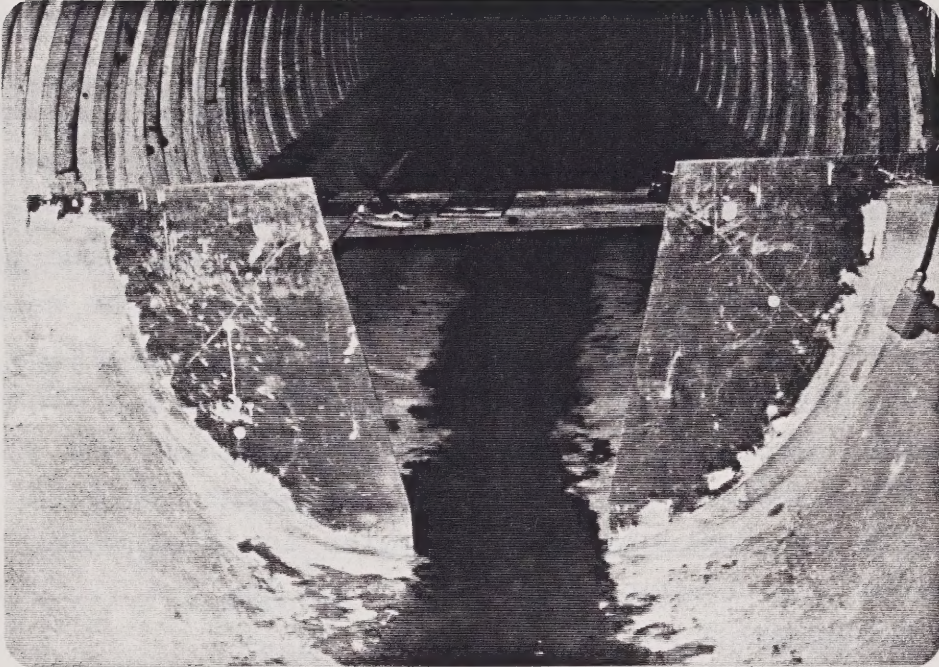


FIGURE 6: INSTALLED COMPOUND WEIR

6.5 Sampling Systems

The sampling system was developed in order to accomplish two major functions as follows:

1. Collect large sample volumes for bench or pilot scale treatability studies.
2. Collect sequential samples for stormwater characterization.

The sample collection system used for stormwater characterization and treatment is schematically shown in Figure 3 and 5-B. The system consisted of a 0.6 kW submersible pump with associated delivery piping. The pumping rate to the surface was 1.0 L/s (13.3 Igpm). The sampling volume was split with 0.7 L/s (9.31 Igpm) discharging sequentially to three 1500 L (330 Imp. gallon) storage tanks and the remaining 0.3 L/s (4.00 Igpm) discharging to a 5 L (1.10 Imp. gallon) wet well with continuous overflow. A Sirco Sampler drew sequential samples for stormwater characterization at 10 minute intervals from the 5 L (1.10 Imp. gallon) container.

Sampling for gross particulate matter or debris was attempted by collecting all accumulated matter on the wooden platform, steel grating, wet well and the approaches in the storm sewer under study. Additional descriptions of the sampling systems are given in Appendix 1.

6.6 Sample Collection

6.6.1 Sample Collection for Treatment Evaluation of Stormwater

Sample collection for evaluation of on-site treatment studies consisted of taking a series of one or two litre samples, depending on the number of test parameters required. Samples were also taken in specifically prepared, sterilized bottles for indicator bacteria analyses. The tank contents generally had some time for natural settling prior to the arrival of study personnel. Settled stormwater was then immediately sampled by syphoning the required sample volume

from about 30 cm below the surface without disturbing the tank contents. For routine treatment evaluation, the sample volume collected was generally as outlined in Figure 7. Treatment studies after each major storm event generally consisted of natural and chemically assisted sedimentation. Three sets of samples had to be taken for complete treatment evaluation, i.e. naturally settled stormwater, remixed (initially settled) stormwater, which provided the best available method for estimating the raw stormwater characteristics of the tank content, and that following chemical flocculation and settling.

Stormwater samples with respect to treatment studies are consequently defined as follows:

1. Raw stormwater represents samples that have been tested immediately following their collection from the storm sewer.
2. Settled stormwater (supernatant) represents samples that have naturally settled for a given time period following their collection from the storm sewer.
3. Remixed stormwater (simulated raw stormwater) represents samples that have been stirred up following natural settling as in (2). These samples served as the baseline for treatment evaluation.
4. Chemically treated stormwater (supernatant) represents samples that have been chemically assisted (flocculation) for settling.

As required, but particularly during the early stages of the study, 20 L (5 gallon) samples, settled or remixed, were also withdrawn from the storage tanks for bench-scale studies such as chemical flocculation and sodium hypochlorite disinfection. Bench-scale data served to guide the subsequent batch treatment studies.

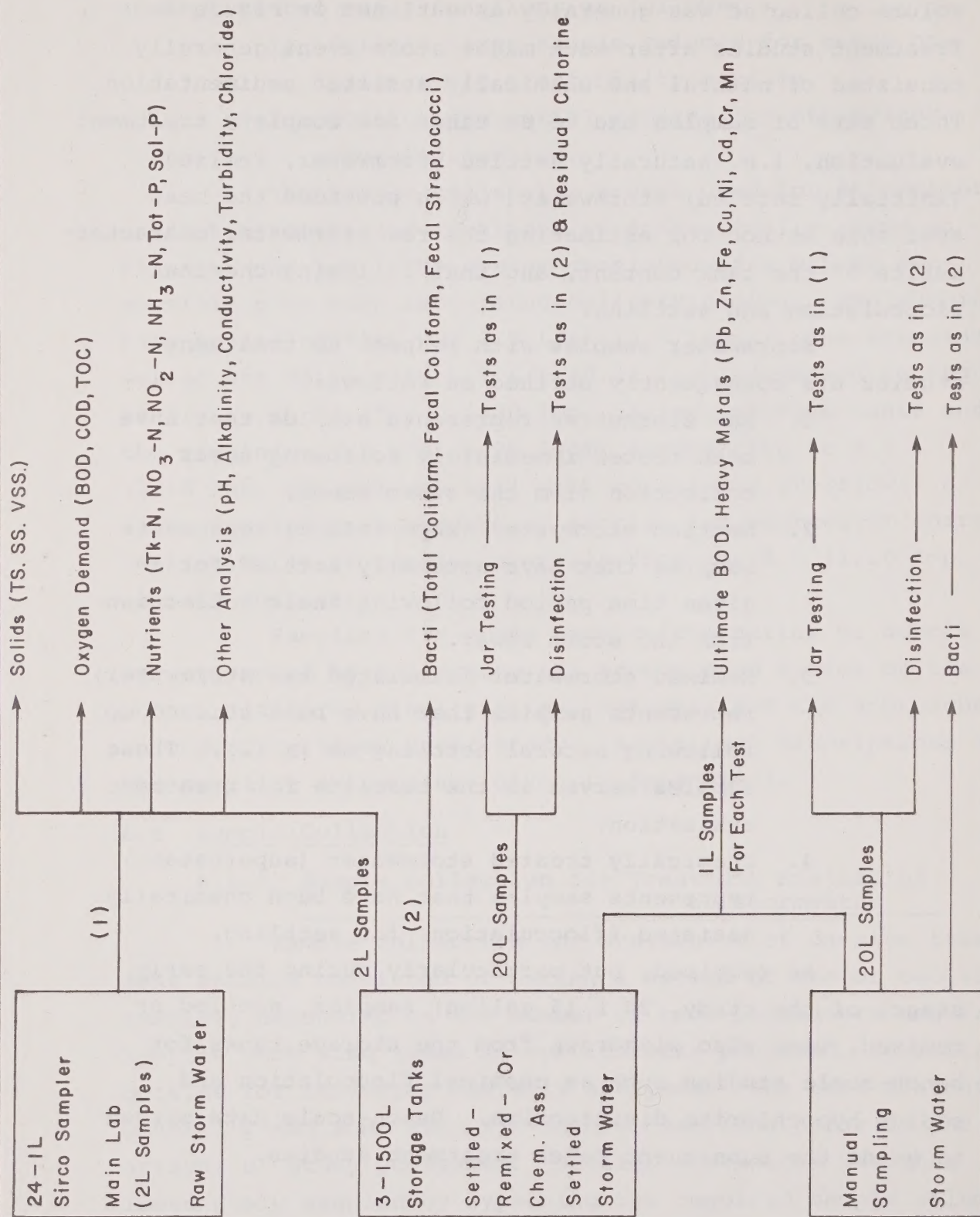


Figure 7 : Sampling and Analysis Program

To evaluate SS reduction following chemically assisted settling ($SS < 15 \text{ mg/L}$), four liter samples were also collected from the treatment tank. Samples for trace metal analysis were collected in one liter plastic bottles to which a preservative (nitric acid) had been added).

6.6.2 Sample Collection for Characterization of Stormwater

Sample collection for stormwater characterization was done automatically by the Sirco sampler. One liter samples were sequentially collected at a ten minute frequency. Generally, to provide sufficient sample volume for all the test parameters shown in Figure 7, each consecutive set of sequential samples was blended and submitted for analysis as a single sample. One liter sequentially collected samples were, however, submitted for analysis whenever fewer than six samples were obtained during short duration storm events. In such cases, fewer test parameters were then requested.

6.6.3 Sample Collection and Preparation of Debris

Gross particulate matter (debris) was collected from the storm sewer dropshaft platform as described in Appendix 1-3. The collected wet matter was taken to the lab and after partial air drying, was bone dried at 105°C in a drying oven. Following drying, the matter was separated into major constituents such as leaves, paper, plastics and wood. Based on the total dry collected matter, the percentage of each portion was calculated.

6.7 Lab and Field Testing

6.7.1 Stormwater Quality Parameters

Details of selected quality parameters used for this study, together with required sample volumes, are summarized in Figure 7. They included suspended solids, oxygen demanding material, nutrients, indicator bacteria and trace metals.

Special test parameters, particularly for treatment evaluations, included 20-day BOD. On one occasion, fresh stormwater was also tested for ultimate BOD.

All routine sample analysis was done at the Ministry of the Environment Central Laboratories in Toronto according to Standard Methods (12) or MOE modified methods (13).

6.7.2 Non-Routine Testing

Non-routine testing, which was done on-site, included the estimation of alum floc settling rates by means of a Secchi disc. The test consisted of lowering the Secchi disc at five-minute intervals to a depth at which the white-black imprint just became extinct when viewed by the eye from above the surface. Readings were taken starting five minutes after slow agitation had stopped. The Secchi disc extinction distances, an indication of the settling rate of the chemical floc layer were then plotted against time.

In addition, the laboratory established an ultimate BOD curve for fresh stormwater using an electrolysis BOD measuring system (14). The toxicity of stormwater was assessed by the BOD test dilution technique.

6.8 Treatment Procedures (Physical/Chemical)

6.8.1 Bench-Scale Treatment Studies

Bench-scale treatment studies included jar testing in preparation for on-site pilot-scale flocculation and disinfection studies. Methodology of these studies is summarized in Appendix 1. On-site jar testing was done to establish the chemical dosage for pilot-scale batch treatment studies. Both alum and ferric chloride were evaluated. Since laboratory tests on these samples were normally not available for about two to three weeks, observations of floc formation, settling rates, clarity of supernatant and floating material served as guidelines for the selection of chemical dosage for pilot studies. This method of chemical dosage selection

was confirmed subsequently by the analytical results. No attempt was made to adjust pH or alkalinity of the stormwater prior to dosing with alum or ferric chloride.

Jar tests were also used to establish NaOCl dosages for disinfection of raw, settled, remixed and chemically treated stormwater. Sufficient NaOCl was applied to maintain a chlorine residual of 0.5 to 1.0 mg/L following a 30 minute contact time. To establish potential bacterial regrowth in disinfected stormwater, samples were dechlorinated and stored for up to 48 hours in uncovered bacti bottles. Details of bench-scale disinfection are given in Appendix 1-5.

6.8.2 Pilot-Scale Treatment Studies

Pilot-scale treatment studies consisting of natural settling, chemical flocculation and disinfection, were done on-site using 1000 to 1300 liter (220 to 286 gallon) batches of stormwater in the previously described treatment tanks.

Pollutant removals by settling were evaluated with both settled and "remixed" stormwater. Settling times following a storm event were usually uncontrollable and varied widely, depending on the arrival of personnel at the site.

In preparation for chemical flocculation, the initially settled stormwater was remixed and sampled for analysis of pollutant concentrations. At the same time, an optional jar test was done on the remixed stormwater to establish the approximate chemical dosage for flocculation. Standard jar test procedures were followed with the exception that a two hour settling time was allowed. The two hour settling period was established from visual observations which were subsequently confirmed by laboratory analysis. Both alum and ferric chloride were evaluated. Details of jar test procedures are given in Appendix 1-5.

On-site pilot treatment studies for the reduction of indicator bacteria included natural settling, chemically assisted settling and disinfection with NaOCl. Bacterial regrowth, with and without dechlorination, was studied for up to 48 hours. The average dosage of NaOCl was established by jar tests on previous storm events.

For batch treatment studies, the required volume of NaOCl (as Javex-5 with known available chlorine concentration) was mixed with the raw or chemically treated stormwater. Following a rapid mix of two minutes, slow agitation was continued for 30 minutes at which time samples were taken in Na₂S₂O₃ preserved bacti bottles. Tests for residual chlorine were also done at this time. If convenient, the disinfected batch was allowed to stand for one or two days in order to assess decay of residual chlorine and potential bacterial regrowth. Although residual chlorine was allowed to decay naturally in the treatment tank, all samples were dechlorinated at the time of sampling. Details of batch disinfection, which is similar to bench-scale disinfection procedures, are provided in Appendix 1-5.

7.0 PRESENTATION AND DISCUSSION OF RESULTS

7.1 Characterization of Urban Runoff

7.1.1 Hydrological Data Analysis

A total of 43 storm events were recorded during the 1977-78 study period. Thirty-five occurred during the period May 21 to October 9, 1977 and eight occurred from April 6 to July 3, 1978. Eighteen of the 1977 events and six of the 1978 events were of sufficient duration to permit meaningful sampling. The remaining events were either too short in duration or too low in intensity. Each storm was numbered sequentially for future reference. Results from a snowmelt runoff characterization and treatment study of this catchment are presented in a separate report (15).

Table 11-1 of Appendix 11 summarizes the hydrologic data for all the storm events recorded. The data includes rainfall depth, duration and average intensity, runoff coefficient, peak storm sewer flow rates, total runoff volume and antecedent dry period.

Rainfall, runoff depth and runoff volume have been plotted in Figures 8, 9 and 10 for all storm events during the 1977 study period. Basically, the figures illustrate the relative variability of the selected parameters including inter-event time. It was decided that rainfall events with greater than a total runoff volume of 800 m^3 (28,500 cu ft) would be classified as large events. Seven such storms occurred during the study period with one having insufficient data for analysis. These events have been identified by their assigned numbers in Figures 8, 9 and 10.

The average runoff coefficient (i.e. runoff depth/rainfall depth) for all events was approximately 0.26. Storm events with greater than 800 m^3 (28,500 cu ft) of runoff had an average runoff coefficient of 0.39 which varied in a range

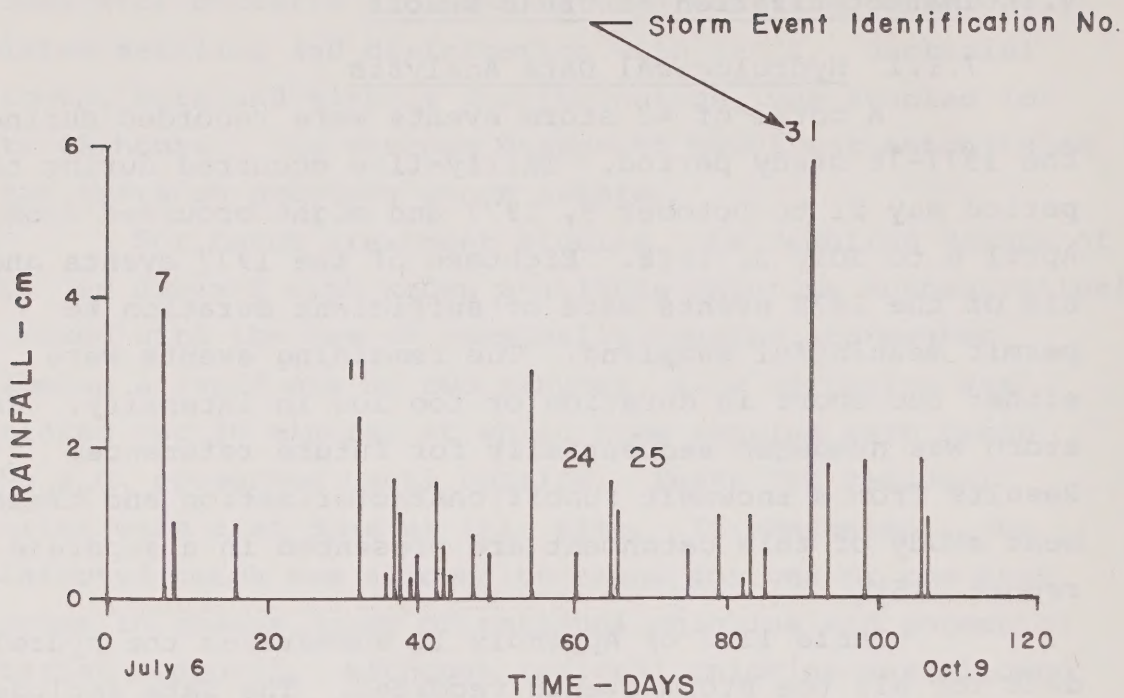


FIGURE 8 : RAINFALL DEPTH FOR ALL STORM EVENTS DURING 1977 STUDY PERIOD.

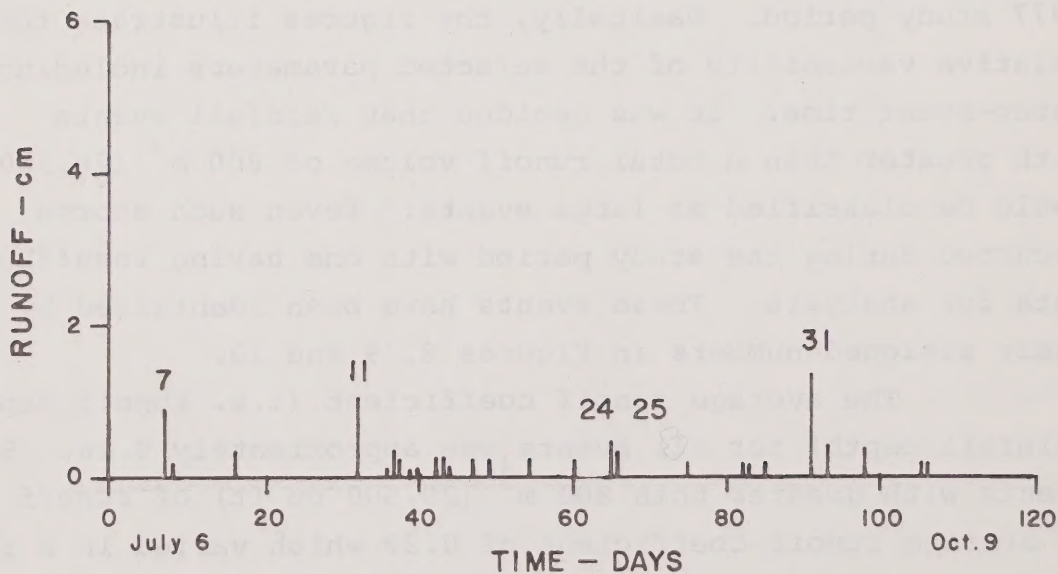


FIGURE 9 : RUNOFF DEPTH FOR ALL STORM EVENTS DURING 1977 STUDY PERIOD.

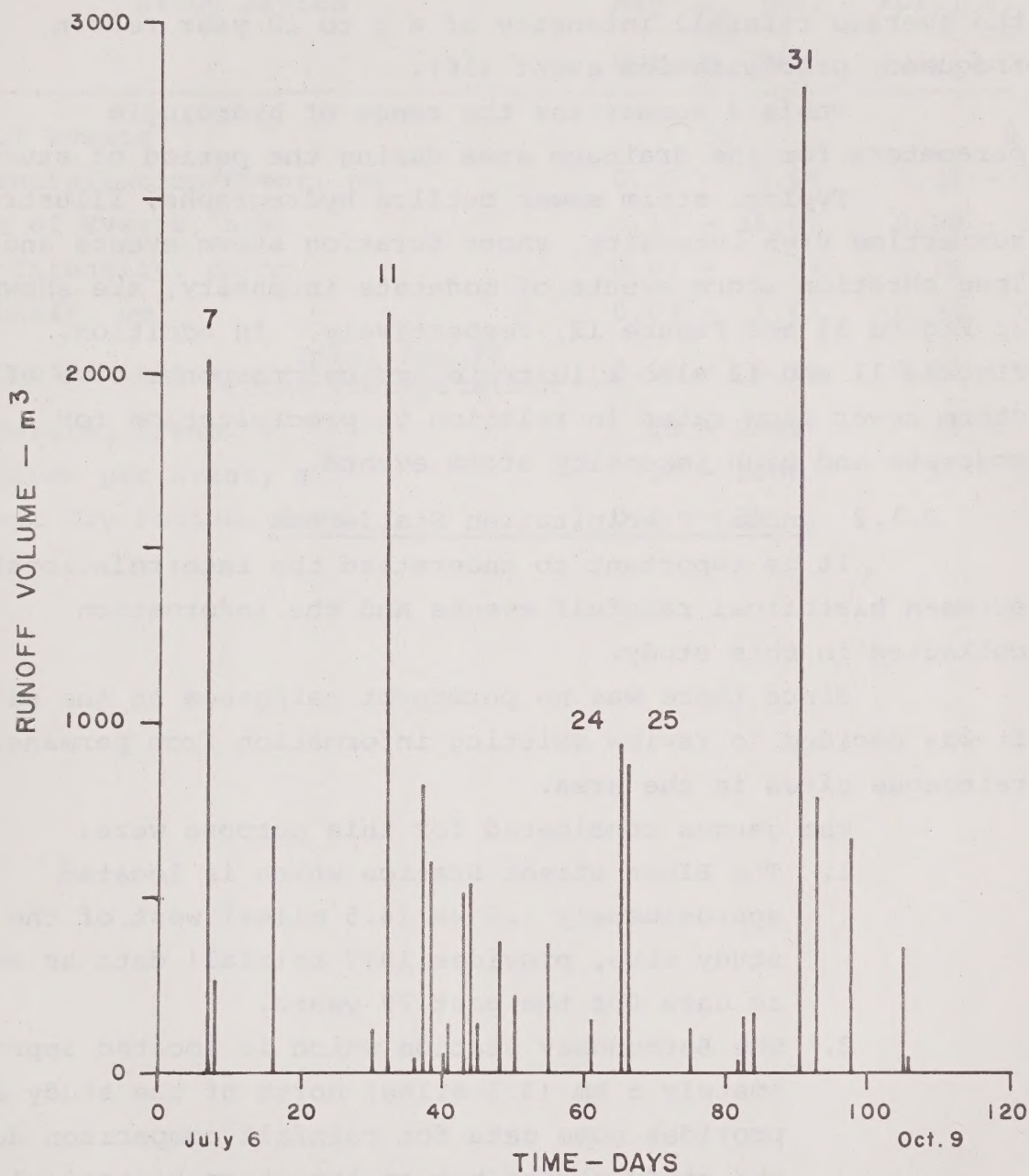


FIGURE 10 : RUNOFF VOLUMES OF ALL STORM EVENTS DURING 1977 STUDY PERIOD.

from 0.29 to 0.55. Computations of the runoff coefficients were based on the net area contributing to runoff. The above values may be compared with runoff coefficients from residential areas which vary from 0.30 to 0.50 based upon the average rainfall intensity of a 5 to 10 year return frequency precipitation event (16).

Table 4 summarizes the range of hydrologic parameters for the drainage area during the period of study.

Typical storm sewer outflow hydrographs, illustrating summertime high intensity, short duration storm events and long duration storm events of moderate intensity, are shown in Figure 11 and Figure 12, respectively. In addition, Figures 11 and 12 also illustrate typical response time of storm sewer flow rates in relation to precipitation for moderate and high intensity storm events.

7.1.2 Annual Precipitation Statistics

It is important to understand the interrelationship between historical rainfall events and the information collected in this study.

Since there was no permanent raingauge on the site, it was decided to review existing information from permanent raingauge sites in the area.

The gauges considered for this purpose were:

1. The Bloor Street Station which is located approximately 7.5 km (4.5 miles) west of the study site, provides 1977 rainfall data as well as data for the past 29 years.
2. The Bermundsey Station which is located approximately 5 km (3.1 miles) north of the study site, provides some data for rainfall comparison during the study period but no long term historical data.

Recorded rainfall at the study site for the period May 1 to October 9, 1977 was 47.17 cm (18.5 inches). For the same period, accumulated rainfall at the Bloor Street and Bermundsey Stations was 59.2 cm (23.2 inches) and 50.1 cm (19.7 inches), respectively, which correspond to 125% and

TABLE 4
RANGE OF HYDROLOGIC PARAMETERS FOR
BARRINGTON DRAINAGE AREA

Study Period	May 31, 1977 to Oct. 9, 1977	April 6, 1978 to July 3, 1978
Number of Events	35	8
Total Precipitation/Event, cm	0.25 - 5.69	0.36 - 1.78
Duration of Events, hrs.	0.17 - 15.00	0.08 - 8.0
Average Intensity, cm/hr	0.07 - 7.97	0.19 - 4.5
Total Runoff, cm	0.03 - 1.62	0.03 - 0.16
Runoff Coefficient ($\frac{\text{Total Runoff}}{\text{Total Precipitation}}$)	0.03 - 0.55	0.03 - 0.14
Peak Flowrate, L/sec.	55 - 2290	45 - 130
Total Volume per Event, m ³	34 - 2808	50 - 278
Antecedent Dry Period, days	0.1 - 30	0.1 - 23

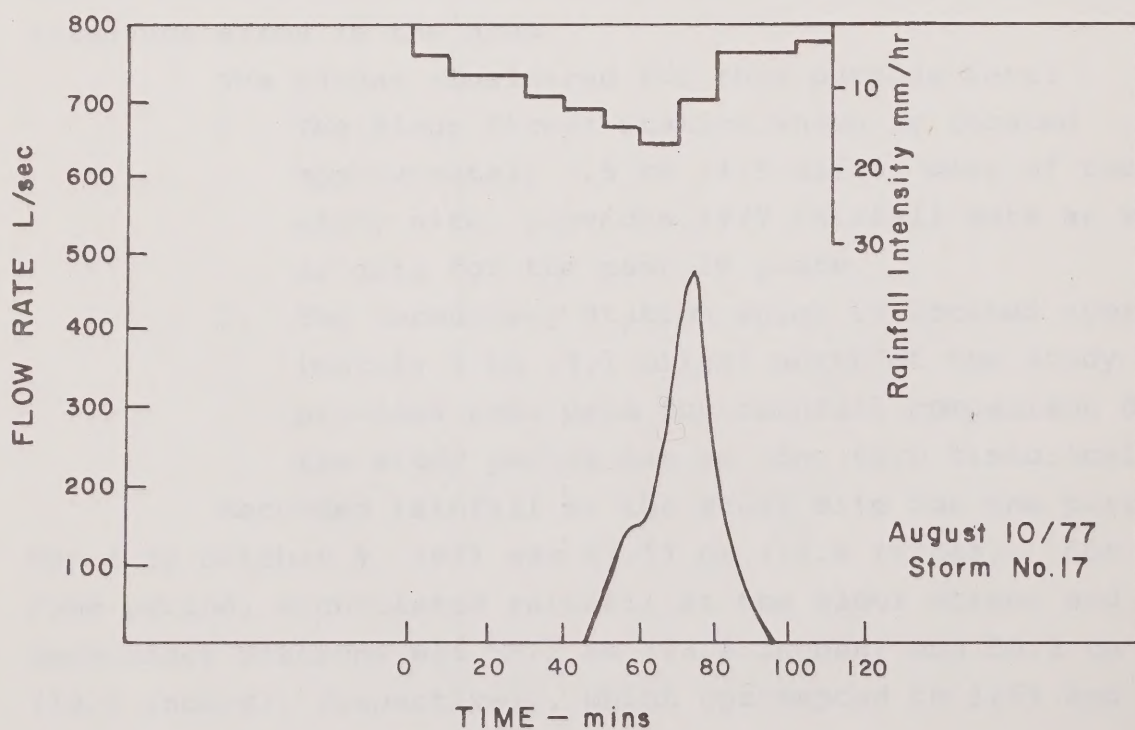
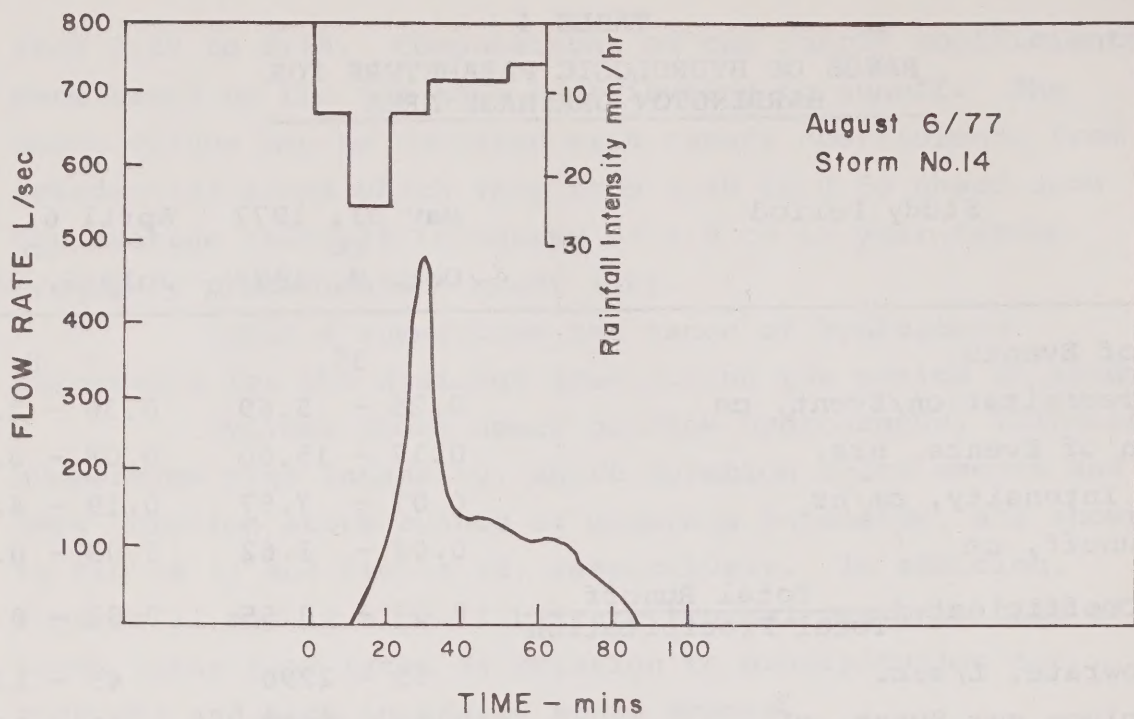


FIGURE II : STORM SEWER HYDROGRAPHS OF TYPICAL SUMMER TYPE, HIGH INTENSITY
-SHORT DURATION STORM EVENTS.

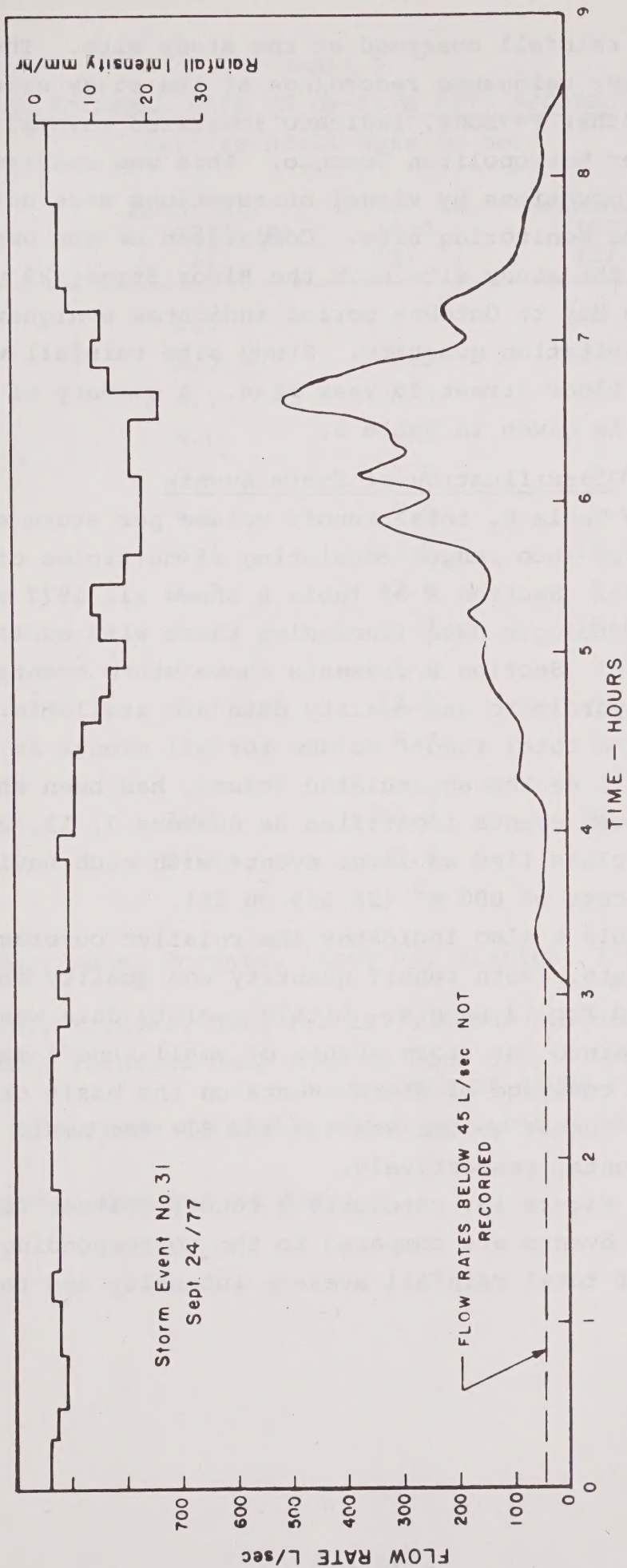


FIGURE 12: STORM SEWER HYDROGRAPH OF VARIABLE INTENSITY, LONG DURATION STORM EVENT.

106% of the rainfall observed at the study site. The somewhat lower raingauge recordings at the study site may, among other reasons, indicate localized rainfall activity over Metropolitan Toronto. This was confirmed on numerous occasions by visual observations made during travel to the monitoring site. Comparison of the observed rainfall at the study site with the Bloor Street 29 year mean for the May to October period indicates a higher than normal precipitation quantity. Study site rainfall was 136% of the Bloor Street 29 year mean. A summary of this information is given in Table 5.

7.1.3 Classification of Storm Events

In Table 6, total runoff volume per storm event is categorized into ranges consisting of multiples of 200 m^3 (7,143 cu ft). Section A of Table 6 shows all 1977 events for which hydrologic data (including those with quality data) are available. Section B presents those storm events for which both hydrologic and quality data are available. In each case, the total runoff volume for all events in the range, as well as the accumulated volume, has been shown.

Storm events identified as numbers 7, 11, 24, 25 and 31 were classified as large events with each having a volume in excess of 800 m^3 (28,500 cu ft).

Table 6 also indicates the relative coverage of observed events. Both runoff quantity and quality data were obtained for 13 events. Little quality data was, however, obtained for storm events of small runoff magnitude. Quality data coverage of storm events on the basis of accumulative runoff volume was 49% and 81% for small ($<800 \text{ m}^3$) and large events, respectively.

In Figure 13, categorized runoff volumes for 29 (1977) storm events are compared to the corresponding means and ranges of total rainfall average intensity and rainfall

TABLE 5
HISTORICAL RAINFALL DATA VS ON-SITE 1977 RECORDED RAINFALL
(all rainfall data in cm)

Month	Bloor St. Mean (1941-70) (1)	Bloor St. 1977 (2)	Bermundsey 1977 (3)	Study Site 1977 (4)
January	2.5	0	-	-
February	2.3	2.2	-	-
March	4.7	6.3	-	-
April	6.0	8.1	-	-
May	7.6	2.5	1.4	1.78
June	6.3	9.0	6.6	7.74
July	8.1	13.9	10.6	8.49
August	6.7	12.4	9.2	11.37
September	6.1	15.7	16.4	13.44
October	6.1	6.1	5.9	4.30
November	5.7	12.8	-	-
December	3.5	6.8	-	-
Total (May-Oct.)	34.5	59.2	50.1	47.17
Total (Year)	64.6	95.8	-	-

- (1) AES, 29 year mean, Toronto, Bloor St. Station, 7.5 km west of study site.
- (2) AES, monthly rainfall data for 1977, Bloor St. Station.
- (3) AES, monthly rainfall data (May to Oct. only). Bermundsey Station, 5 km north of study site.
- (4) Includes only those rainfalls which produced a measurable runoff.

AES - Atmospheric Environment Service

TABLE 6

RUNOFF VOLUMES ACCORDING TO CATEGORIZED STORM EVENTS - 1977

Runoff Volume Range - m ³	No. of Events	Total Volume Per Range - m ³	Accumulated Volume - m ³
A - All 1977 events for which hydrologic data are available			
0 - 199	11	1,173	1,173
200 - 399	5	1,564	2,737
400 - 599	3	1,641	4,378
600 - 799	3	2,354	6,732
800 - 999	3	2,640	9,372
1,000 - 3,000	4	8,263	17,635
Total	29	17,635	-

B - Events for which both hydrologic and quality data are available

0 - 199	1	34	34
200 - 399	3	945	979
400 - 599	3	1,641	2,620
600 - 799	1	662	3,282
800 - 999	2	1,827	5,109
1,000 - 3,000	3	7,007	12,116
Total	13	12,116	-

LEGEND

○ ARITHMETIC MEAN

— RANGE

NUMBER OF EVENTS

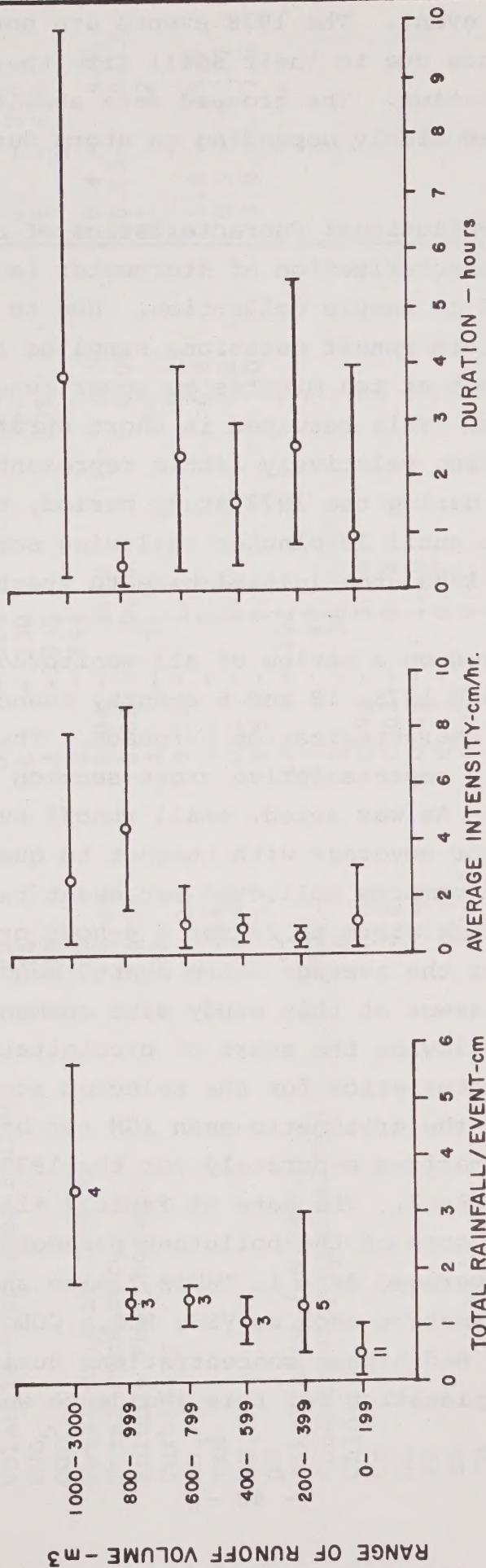


FIGURE 13 : COMPARISON OF RANGED RUNOFF VOLUMES WITH TOTAL RAINFALL, AVERAGE INTENSITY, AND RAINFALL DURATION.

duration per event. The 1978 events are not included in Figure 13 since due to their small size they contributed little information. The grouped data show that runoff volumes varied widely depending on storm duration and intensity.

7.1.4 Pollutional Characteristics of Stormwater

Characterization of stormwater is highly dependent on the method of sample collection. Due to the unpredictability of storm runoff duration, sampling frequency was arbitrarily set at ten minutes to cover runoff periods of up to 4 hours. This resulted in short duration runoff events receiving relatively little representative sampling. In addition, during the 1977 study period, the first sample was not taken until 10 minutes following sampler activation while during 1978, the initial time to start sampling was one minute.

Based on a review of all monitored storm events during 1977 and 1978, 18 and 6 events, respectively, were selected for characterization purposes. The selected events cover a representative cross-section of observed storm events. As was noted, small runoff events received relatively poor coverage with respect to quality aspects. The number of samples collected per event ranged from two, for a very short storm to 24 for a 4-hour or longer event. Typically, for the average storm event, measurable runoff in the storm sewer at this study site commenced about 10 minutes following the start of precipitation. Stormwater quality characteristics for the selected storm events, consisting of the arithmetic mean (GM for bacteria) and range are summarized separately for the 1977 and 1978 study periods in Table 7. The data of Table 7 illustrate the wide variations of some of the pollutant parameters. An examination of the averaged data in Table 7 also shows that pollutant parameters such as VSS, BOD₅, COD, Total-P, TKN and turbidity had higher concentrations during 1978. No reasonable explanation for this incidence was established.

TABLE 7

SUMMARY OF RAW STORMWATER POLLUTANT CONCENTRATIONS

(unless stated otherwise all data are in mg/L)

Pollutant	Study Period			
	1977 - 18 Events		1978 - 6 Events	
	Mean of All Events	Range of All Events	Mean of All Events	Range of All Events
Total Solids	756	66 - 6980	527	148 - 1430
Suspended Solids	281	8 - 2165	297	45 - 1090
Volatile Suspended Solids	65	6 - 365	164	67 - 358
BOD ₅	14	2 - 130	66	6 - 250
COD	138	13 - 1035	299	55 - 640
Total Organic Carbon	30	3 - 244	-	-
Total Phosphorus	0.48	0.04 - 1.40	1.36	0.4 - 4.7
Soluble Phosphorus	0.06	0.02 - 0.60	0.06	0.02 - 0.12
Turbidity	21	4 - 71	40	21 - 92
NH ₃ -N	0.26	0.10 - 1.3	0.17	-
TKN	2.2	0.5 - 7.5	6.4	-
NO ₃ -N	0.46	0.1 - 1.4	0.21	-
pH	7.2	6.5 - 7.6	7.0	-
Alkalinity (as CaCO ₃) ²	37	- 102	-	-
Conductivity (μmhos/cm ²)	143	- 48	-	-
Chloride	9	- 58	-	-
Cu	0.05	0.02 - 0.04	-	-
Ni	0.03	0.02 - 0.06	-	-
Pb	0.57	0.29 - 1.00	-	-
Zn	0.33	0.15 - 0.60	-	-
Cd	0.006	0.005 - 0.01	-	-
Cr	0.04	0.04 - 0.08	-	-
Mn	0.14	0.06 - 0.27	-	-
Fe	5.46	1.90 - 11.00	-	-
Tot. Col.	-	7.0x10 ⁴ - 3.2x10 ⁶	-	-
Fec. Col	-	3.0x10 ³ - 2.7x10 ⁴	-	-
Fec. Strep.	-	1.3x10 ³ - 7.1x10 ⁴	-	-

Trace metal concentrations from 13 individual storms are also summarized in Table 7. Trace metal concentrations for individual events are given in Table 11-7 of Appendix 11. Samples for these analyses were obtained in combination with ongoing treatment studies representing well mixed, 1000 L (200 gallon) sample batches which were collected for the duration or first 30 minutes of the storm events. With the exception of iron, all trace metals were below the criteria set forth in the model Industrial Waste Discharge Bylaw for Municipal Sewers (17).

Samples for bacteriological analysis were only collected during ongoing events when staff were onsite. Generally, bacterial concentrations within each group displayed relatively little variation as indicated in Table 11-6 of Appendix 11. These observations were also substantiated on samples taken from remixed and naturally settled stormwater which showed little change in relationship to fresh stormwater. Pollutant characteristics for individual storm events are shown in Tables 11-2 to 11-7 of Appendix 11. Average 1977 stormwater quality agreed fairly well with typical quality determination in other Ontario studies (Table 1).

The composition of debris collected and segregated into constituent fractions such as plastics, paper, wood and leaves are shown in Table 8. The percentage of each constituent is based on the total weight of collected debris that was captured following the indicated storm events. The debris collected does not necessarily represent the total quantity of debris washed into the sewerage system. Some indication of the relative fractions of debris collected are presented in Figure 14. A comparison of the mass of collected debris with corresponding runoff volume shows that storm events with higher runoff volumes tend to transport more debris. About 50% of all collected debris consisted of leaves.

TABLE 8

DEBRIS CLASSIFICATION IN URBAN RUNOFF

Storm No.	% of Debris by Weight					Total Sample Weight gm	Runoff Volume m ³
	Plastic	Paper	Wood	Leaves	Other		
3	11.2	14.6	31.8	42.5	-	1085	-
4	15.0	21.5	7.1	56.4	-	1531	1256
5	20.9	20.0	15.9	43.2	-	1152	-
7	9.0	11.6	10.7	60.9	7.9	1838	2038
9	10.8	11.8	28.9	41.1	7.4	1415	710
11	10.3	6.2	20.9	51.6	11.0	3496	2161
13-14	13.3	12.5	26.5	47.7	-	824	1408
20	14.4	24.1	12.1	49.4	-	990	360
22	12.9	12.8	19.1	55.2	-	716	370
Average	13.1	15.0	19.2	49.8	2.9	1450	

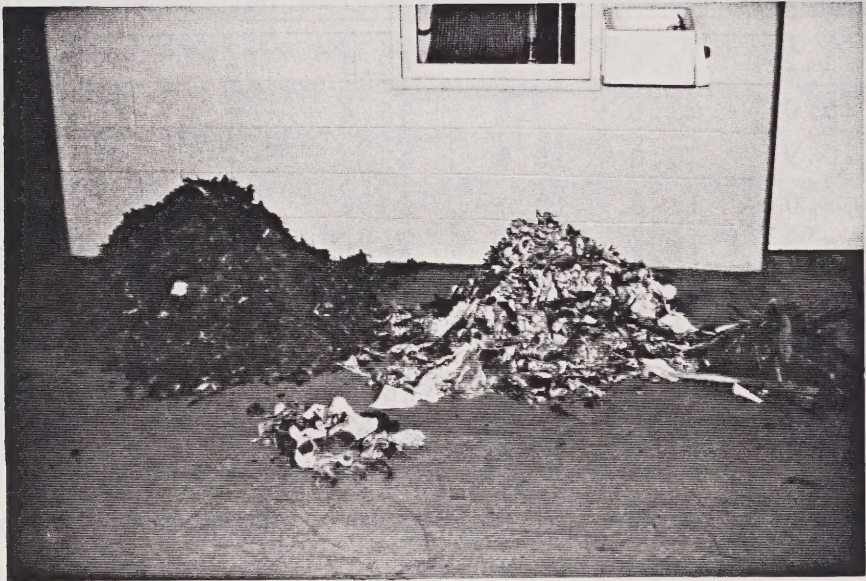


FIGURE 14: STORM SEWER DEBRIS

Testing of ultimate BOD indicated that for all practical purposes, BOD₅ existed in the carbonaceous form only. No nitrogenous demand was observed. BOD dilution techniques carried out on three occasions using five different dilutions each time indicated no evidence of stormwater toxicity toward bacteria. The average ratio BOD₂₀/BOD₅ of 3.7 shows that only about one-quarter of the potential BOD exerts a short term oxygen demand (data extracted from Table 13 of Section 7.3.1.2). The ratio also suggests a potential long term effect of the substrate in stormwater upon the receiving water.

7.1.5 Factors Affecting Pollutant Concentrations

The relationship of rainfall to runoff, pollutant concentrations and mass pollutant flows is illustrated in Figures 15 and 16 for two typical storm events. Inspection of the results shows that pollutant concentrations varied reasonably well with rainfall intensity and runoff rate. Peak pollutant concentrations were not necessarily confined to the initial portion of a runoff event. The storm event presented in Figure 15 illustrates the effect of subsequent runoff peaks on pollutant concentration. Typically, very high intensity runoff events were of short duration. Long duration storm events were generally of lesser intensity with more moderate peak flows.

7.2 Pollutant Mass Loadings

Pollutant mass loadings for the 13 storm events for which both satisfactory flow measurement and sampling data are available, are reported in Tables 9 and 10. Table 9 represents the actual pollutant mass load discharged per storm event as well as the total mass for the indicated events. Pollutant mass loadings per unit area are similarly shown in Table 10. Pollutant mass loads were computed by flow weighting the average concentration for each 10 or 20 minute segment of the hydrograph. Recorded runoff duration for each event is also presented in Table 10.

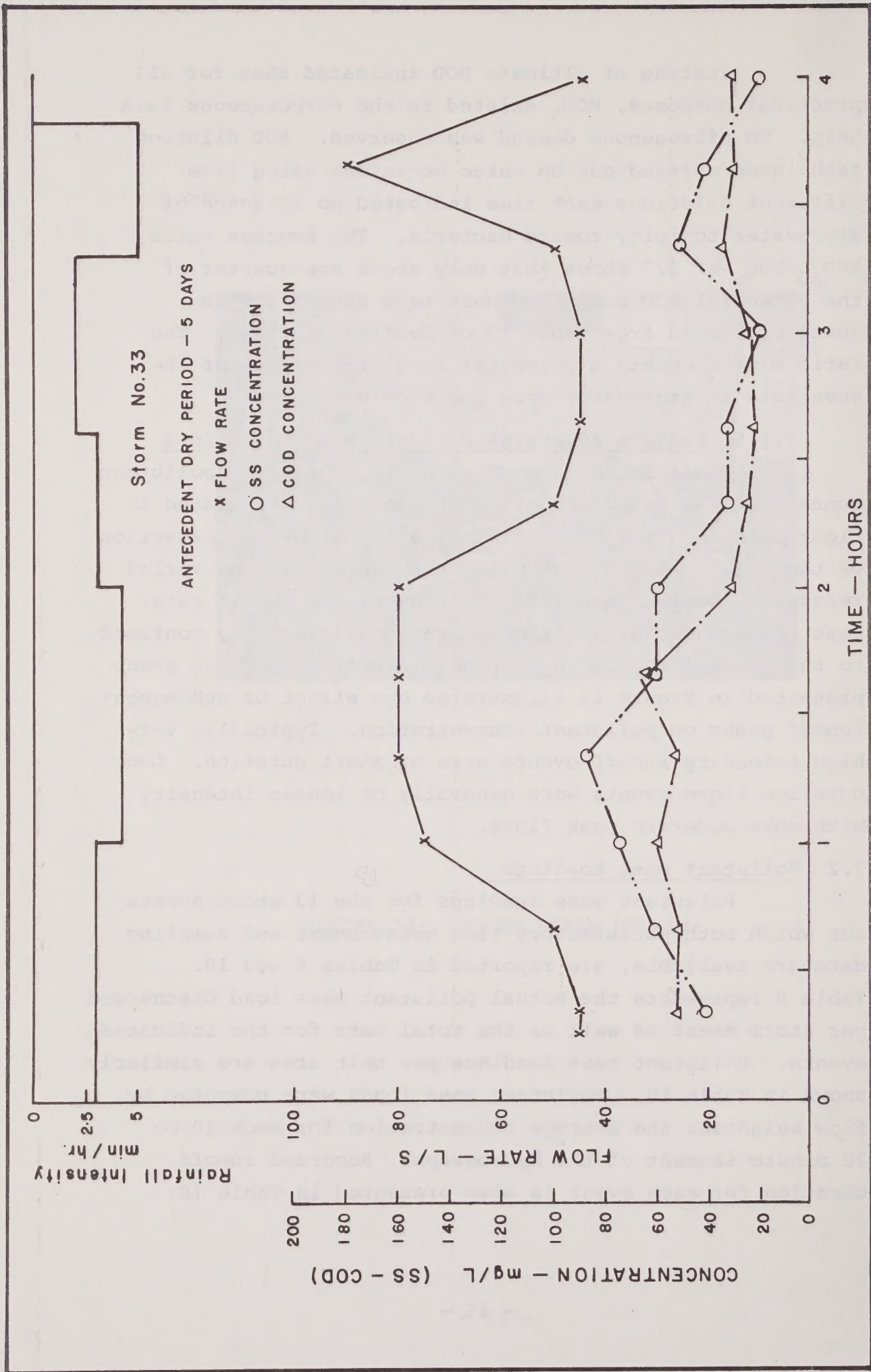


FIGURE 15 : EFFECT OF RAINFALL INTENSITY ON STORM SEWER HYDROGRAPH AND SELECTED POLLUTOGRAPHS .
LOW INTENSITY - LONG DURATION EVENT.

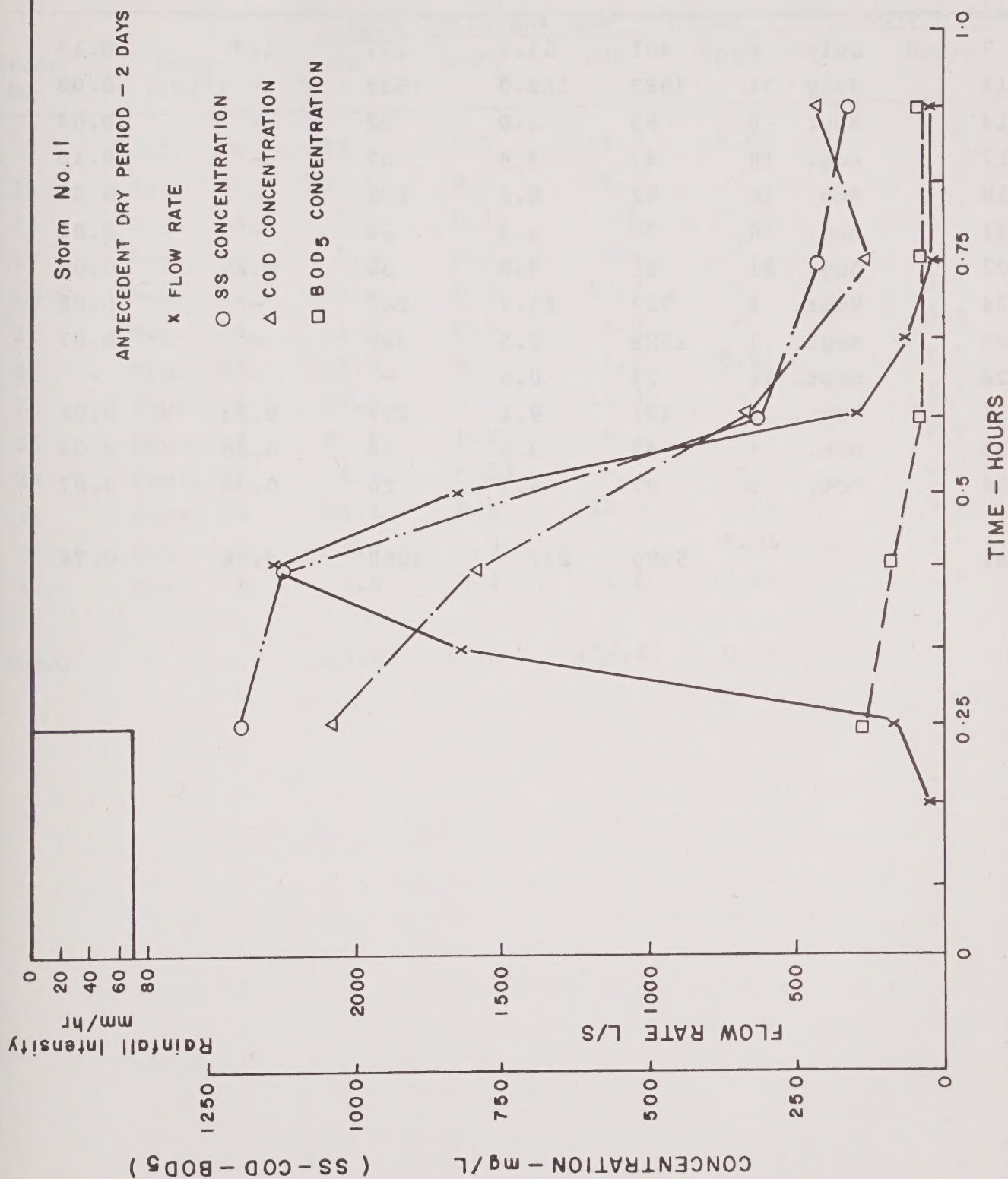


FIGURE 16 : EFFECT OF RAINFALL INTENSITY ON STORM SEWER HYDROGRAPH AND SELECTED POLLUTOGRAPHS .
TYPICAL SUMMERTIME HIGH INTENSITY - SHORT DURATION EVENT.

TABLE 9

POLLUTANT MASS DISCHARGES FOR 13 STORM EVENTS - 1977

Storm No.	Date		Total Pollutant Load - kg				Soluble-P
			SS	BOD ₅	COD	Total-P	
7	July	6	401	11.4	257	1.7	0.13
11	July	31	1983	169.0	1537	-	0.08
14	Aug.	6	53	2.0	32	-	0.04
17	Aug.	10	47	3.4	37	-	0.10
18	Aug.	10	92	5.2	232	-	0.05
21	Aug.	16	30	1.3	34	-	0.01
22	Aug.	21	51	3.8	30	0.25	0.03
24	Sept.	1	727	11.7	249	-	0.08
25	Sept.	1	1528	9.5	349	-	0.07
28	Sept.	16	23	0.5	-	-	-
31	Sept.	24	421	9.1	277	0.83	0.05
33	Oct.	1	47	3.6	38	0.28	0.03
34	Oct.	8	87	6.7	26	0.30	0.07
Total			5490	237	3098	3.36	0.74

TABLE 10

POLLUTANT MASS DISCHARGES IN MASS/UNIT AREA (13 STORM EVENTS)

(Based on Net Area of 17.4 ha)

Storm No.	Date (1977)		Unit Pollutant Load - kg/ha				Recorded Runoff Time
			SS	BOD ₅	COD	Total-P	hours
7	July	6	23.1	0.7	14.7	0.09	2.8
11	July	31	114.1	9.7	88.3	-	1.0
14	Aug.	6	3.0	0.1	1.8	-	1.3
17	Aug.	10	2.7	0.1	2.1	-	0.8
18	Aug.	10	5.4	0.3	13.3	-	0.8
21	Aug.	16	1.7	0.1	2.0	-	0.8
22	Aug.	21	2.9	0.3	1.7	0.01	1.1
24	Sept.	1	42.0	0.7	14.4	-	1.3
25	Sept.	1	87.8	0.5	20.1	-	2.0
28	Sept.	16	1.3	0.03	-	-	0.7
31	Sept.	24	24.1	0.5	15.9	0.05	5.6
33	Oct.	1	2.7	0.3	2.2	0.01	3.6
34	Oct.	8	5.0	0.4	1.6	0.01	1.0
Total			315.8	13.6	178.8	0.18	-

Pollutant mass loadings are also presented according to ranked runoff volume in Table 11. Storms with a runoff volume of 800 m^3 (28,500 cu ft) or greater have significantly higher levels of mass loadings. Inspection of the accumulated mass, shown per range and also on an overall accumulated mass, clearly shows that the bulk of the pollutant mass, particularly suspended solids, are linked with storm events each having a runoff volume in excess of 800 m^3 (28,500 cu ft) or $35 \text{ m}^3/\text{ha}$ (510 cu ft/acre). Of the 13 observed events shown in Table 11, which represents a typical cross-section of the encountered type of events, 92%, 88% and 86% of the suspended matter, BOD_5 and COD respectively, are contained in the five events, each having a runoff volume in excess of 800 m^3 (28,500 cu ft). Total runoff volume from these five events corresponds to 73% of the total observed runoff volume, i.e. from the 13 events for which both quality and hydrologic data were available. Although data for observed storm events (Table 11) are highly skewed toward the larger events, i.e. events with a runoff volume in excess of 800 m^3 , a comparison based on Tables 6 and 11 indicates that complete coverage of all storm events (on a volume basis) would not substantially change the relative pollutant mass distribution. No first flush phenomenon was demonstrated on the basis of the observed relative accumulative SS mass loads and runoff volumes.

7.3 Treatment Studies

7.3.1 Natural and Chemically Assisted Settling

7.3.1.1 Bench-Scale Treatment Studies

Percentage pollutant removals of SS, BOD_5 , COD and Total-P by flocculation and/or sedimentation are shown in Table 12. Both alum and ferric chloride performed about equally well. Percent pollutant removals by chemical flocculation as shown in Table 12 correspond to the selected

TABLE 11

OBSERVED POLLUTANT MASS LOADS IN RELATION TO RUNOFF VOLUME

(Based on Net Area of 17.4 ha)

Range m ³	No. of Events	Total Mass Per Range - kg/ha		Accumulated Mass - kg/ha		
		SS	BOD ₅	SS	BOD ₅	COD
0-199	1	1.3	0.03	1.3	0.03	-
200-399	3	9.5	0.72	10.8	0.75	5.2
400-599	3	11.1	0.52	21.9	1.27	22.4
600-799	1	4.0	0.26	25.9	1.53	24.6
800-999	2	129.6	1.17	155.5	2.70	59.1
1000-3000	3	161.3	10.83	316.8	13.53	178.1

TABLE 12

SUMMARY OF JAR TEST RESULTS - CHEMICAL COAGULATION OF REMIXED STORMWATER

Storm No.	Coagulant	Dosage-mg/L Range Selected	Remixed SW Conc.-mg/L				% Removal-Settling Only				% Removal-Chem. Floc.			
			SS	BOD ₅	COD	Total P	SS	BOD ₅	COD	Total P	SS	BOD ₅	COD	Total P
<u>1977</u>														
3	Alum	60-80	97	25	130	-	64	12	24	-	99	48	56	-
3	FeCl ₃	50-70	97	25	130	-	-	-	-	-	99	52	52	-
7	Alum	20-60	240	5	105	0.78	96	68	81	85	99	92	90	95
7	FeCl ₃	10-30	240	5	105	0.78	-	-	-	-	99	92	85	90
13	Alum	30-50	172	32	158	0.77	65	13	51	48	97	78	63	92
13	FeCl ₃	30-40	172	32	158	0.77	-	-	-	-	97	50	66	95
21	Alum	30-50	115	9	57	0.34	-	-	-	-	99	78	61	76
22	Alum	20-40	190	2.5	80	0.52	87	52	70	69	99	52	75	92
22	FeCl ₃	20-30	190	2.5	80	0.52	-	-	-	-	99	52	75	96
23	Alum	10-30	305	12	160	1.10	-	-	-	-	99	58	78	91
<u>1978</u>														
36	Alum	20-60	156	16	120	0.76	38	25	41	42	97	44	83	84
37	Alum	20-60	695	26	370	1.30	78	0	57	54	99	23	80	95
Avg. Alum														
							71	28	54	60	99	53	73	89
Avg. FeCl ₃														
							-	-	-	-	99	62	70	95

dosage of alum and/or ferric chloride which were, in most cases, simultaneously evaluated on stormwater from the same event. Corresponding pollutant removals by natural settling are also included in Table 12.

The results clearly show that chemical flocculation and settling of stormwater with alum or ferric chloride achieved consistently higher pollutant removals for equal settling times when compared to natural settling. Variable trends in natural settling characteristics from one storm event to another, also illustrated in Table 12, were essentially eliminated by chemically assisted settling.

Typically, SS are reduced by 99% and 77% for chemically assisted and natural settling, respectively. The relatively high removals of COD and Total-P suggest that these material are largely present in the suspended form.

Chemical dosages required for coagulation of remixed stormwater varied from 20 to 60 mg/L for alum as $\text{Al}_2(\text{SO}_4)_3 \cdot 14 \text{H}_2\text{O}$ and 10 to 50 mg/L for ferric chloride as Fe^{+3} .

Results of bench-scale disinfection are presented and discussed in Section 7.3.2 under Stormwater Disinfection.

7.3.1.2 Pilot-Scale Treatment Studies

Percentage pollutant removal of on-site, pilot-scale treatment studies are shown in Tables 13 and 14. Eight pilot treatment studies of separate storm events of varying magnitude were performed during 1977. Treatment results of four smaller 1978 storm events are also included in Tables 13 and 14. For reference purposes, the respective remixed stormwater concentrations for each treatment batch of approximately 1000 liters (220 gallons) are also included in Tables 13 and 14.

TABLE 13

SUMMARY OF ON-SITE BATCH TREATMENT STUDIES
NATURAL AND CHEMICALLY ASSISTED SETTLING

Storm No.	Remixed SW Conc.-mg/L				Settling Time (1) (hours)	% Removal by Settling Only				% Removal by Chem. Coag.				Alum mg/L		
	BOD ₅	BOD ₂₀	COD	TOC		BOD ₅	BOD ₂₀	COD	TOC	BOD ₅	BOD ₂₀	COD	TOC			
(1977)																
(Aug. 16-Oct. 1)																
21	9	20	57	17	12	67	30	25	0	33	82	55	54	65	91	30
22	2.5	22	50	18	12	0	36	83	44	47	68	75	68	72	91	20
23	12	55	160	45	45	50	36	74	64	84	58	60	79	69	94	30
24	10	45	120	23	18	35	56	70	39	65	80	89	83	52	91	30
26	36	90	246	86	50	44	38	58	72	63	44	41	58	70	54	30
27	7	48	59	21	11	0	23	34	29	12	43	60	66	48	75	30
31	4	21	65	26	9	50	62	69	85	50	90	79	32	88	96	20
33	5.5	22	58	13	42	45	5	40	38	37	78	55	57	69	76	30
Mean	10.8	40	106	31	-	36	36	57	46	49	68	64	62	66	88	-
Std. Dev.	10.7	25	68	24	-	24	18	21	27	22	18	16	16	12	9	-
(1978)																
Apr. 6-July 3)																
36	13	-	120	46	9	23	-	44	50	27	31	-	77	72	83	40
37	26	-	370	49	9	15	-	65	0	52	46	-	77	49	-	40
38	16	65	140	13	20	53	48	63	8	50	38	62	84	15	87	30
43	59	150	170	48	13	15	29	29	42	44	32	57	47	44	70	30
Mean	29	108	200	39	-	27	39	50	25	43	37	60	71	45	80	-
Std. Dev.	21	-	115	17	-	18	-	17	25	11	7	-	17	23	9	-

* Turbidity in ftu

(1) Time for natural settling (chemically assisted settling was fixed at 2 hours in all cases)

TABLE 14

SUMMARY OF ON-SITE BATCH TREATMENT STUDIES
NATURAL AND CHEMICALLY ASSISTED SETTLING

Storm No.	Remixed SW Conc.-mg/L					% Removal by Settling Only					% Removal by Chem. Coag.				
	TS	SS	VSS	Total P	TKN	TS	SS	VSS	Total P	TKN	TS	SS	VSS	Total P	TKN
<u>(1977)</u>															
21	244	129	39	0.34	1.2	27	83	77	41	33	43	98	97	41	33
22	272	185	47	0.52	1.8	62	90	85	65	55	66	97	96	92	78
23	410	305	76	1.10	5.2	68	94	89	76	73	70	97	-	91	85
24	460	395	79	0.90	5.0	82	95	92	76	76	85	99	99	98	84
26	530	335	103	1.20	5.0	64	93	96	73	56	55	92	87	73	60
27	195	92	25	0.45	1.5	57	78	40	44	0	40	93	96	87	60
31	335	196	44	0.10	1.8	90	90	86	0	78	87	99	98	60	89
33	226	84	28	0.36	1.6	60	80	71	0	36	60	86	86	89	75
Mean	334	215	55	0.62	2.9	64	88	80	47	51	63	95	94	79	71
Std. Dev.	121	117	28	0.40	1.8	19	7	18	32	27	17	5	5	20	19
<u>(1978)</u>															
36	372	162	50	0.34	2.8	26	57	56	0	50	38	89	86	71	71
37	892	695	266	1.30	6.0	58	87	86	54	50	58	98	96	88	75
38	340	174	73	0.58	2.2	41	81	77	66	45	53	97	96	93	73
43	375	105	60	0.76	3.2	49	67	58	34	44	39	86	83	84	81
Mean	487	284	112	0.75	3.6	44	73	69	39	47	47	93	90	84	75
Std. Dev.	270	276	103	0.41	1.7	14	4	15	29	3	10	6	7	9	4

Range of natural settling times: 9 to 50 hours

Range of alum dosage : 20 to 40 mg/L, followed by 2 hours of settling

Percentage pollutant removal by natural settling is based on the respective settling time as shown in Table 13. The wide range of settling times reflect the elapsed time from the completion of automated sampling to the arrival of personnel on-site. The method of sample collection for these studies is described in Section 6.6 and Appendix 1.

Testing, consisting of chemical flocculation followed by settling, was always performed on remixed, initially settled stormwater. Remixed stormwater also served as the baseline for percentage pollutant reductions for both naturally and chemically assisted settling. Based on jar test results, and preliminary pilot treatment studies, alum was the preferred flocculant. Ferric chloride, although occasionally used, (not shown in Tables 13 and 14) did not consistently perform satisfactorily. This is contrary to bench-scale tests where both ferric chloride and alum performed equally well. Alum dosage was established in the range from 20 to 30 mg/L. Preliminary pilot-scale treatment studies on the basis of settling tests and visual observations, indicated a two hour quiescent settling time of the alum floc within the treatment tank.

With the exceptions noted below, the established alum dosages and settling time were consistent throughout the study period. Storm events following catchbasin cleaning and the final snowmelt demanded higher chemical dosages, particularly if a substantial reduction of turbidity and BOD₅ was required. Based on visual observations, runoff from the latter two conditions was unusually dirty. The higher pollutant concentrations were substantiated by laboratory analyses (storm events no. 26 and 37).

Inspection of the 1977 treatment data in Tables 13 and 14 shows that average SS removal is at about 88% and 95% for natural and chemically assisted settling respectively. Chemical flocculation does not always achieve substantially higher removal of SS over natural settling. The additional

removal of Total-P, TKN, BOD_5 , BOD_{20} , TOC and turbidity is, however, apparent indicating that some of these pollutants are largely present in colloidal form. Settling time in the range from 9 to 50 hours indicated no relationship to pollutant removal. According to the results attained by settling only, it is felt that no additional substantial pollutant removals occur beyond a ten hour settling time.

Alkalinity or pH were not substantially changed under the prevailing alum dosages.

Bench-scale pollutant removals by alum flocculation compared reasonably well with pilot-scale results as is illustrated by comparison of Tables 12 with 13 and 14, although suspended solids removal by natural settling appears enhanced at the pilot-scale level. This is likely due to the extended settling time compared to the standard 30 minute jar test. Seasonal effects on treatment response were not established during the study period (15).

Percentage suspended solids removal for the eight 1977 batch treatment studies are also presented in Figure 17 in relation to remixed stormwater concentrations. Above 200 mg/L, solids concentration exerts little effect upon removal efficiency for either natural or chemically assisted settling.

Figure 18 shows the distribution of percentage reduction of SS and BOD_5 for both natural and chemically assisted settling. Each point in Figure 18 represents the result from a single on-site batch treatment study. The relative slopes of the approximate best fit lines illustrate the variability of the results. A steeper slope indicates greater variability. Suspended solids removal by chemical flocculation has the least variability indicating that SS reduction responded well at all times to chemical flocculation. BOD_5 removal exhibits a wider treatment variability from one event to another, likely due to the varying proportions of BOD_5 in soluble form.

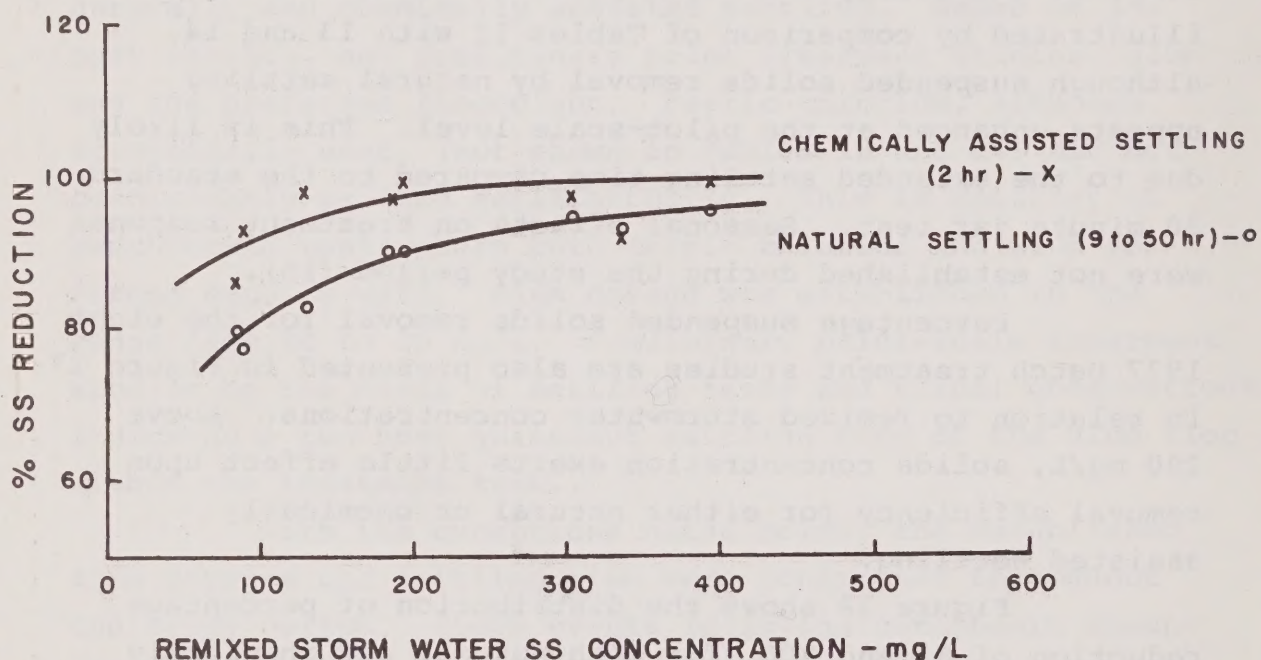


FIGURE 17 : PERCENT SS REDUCTION Vs REMIXED STORM WATER CONCENTRATION
1977 TREATMENT DATA ONLY

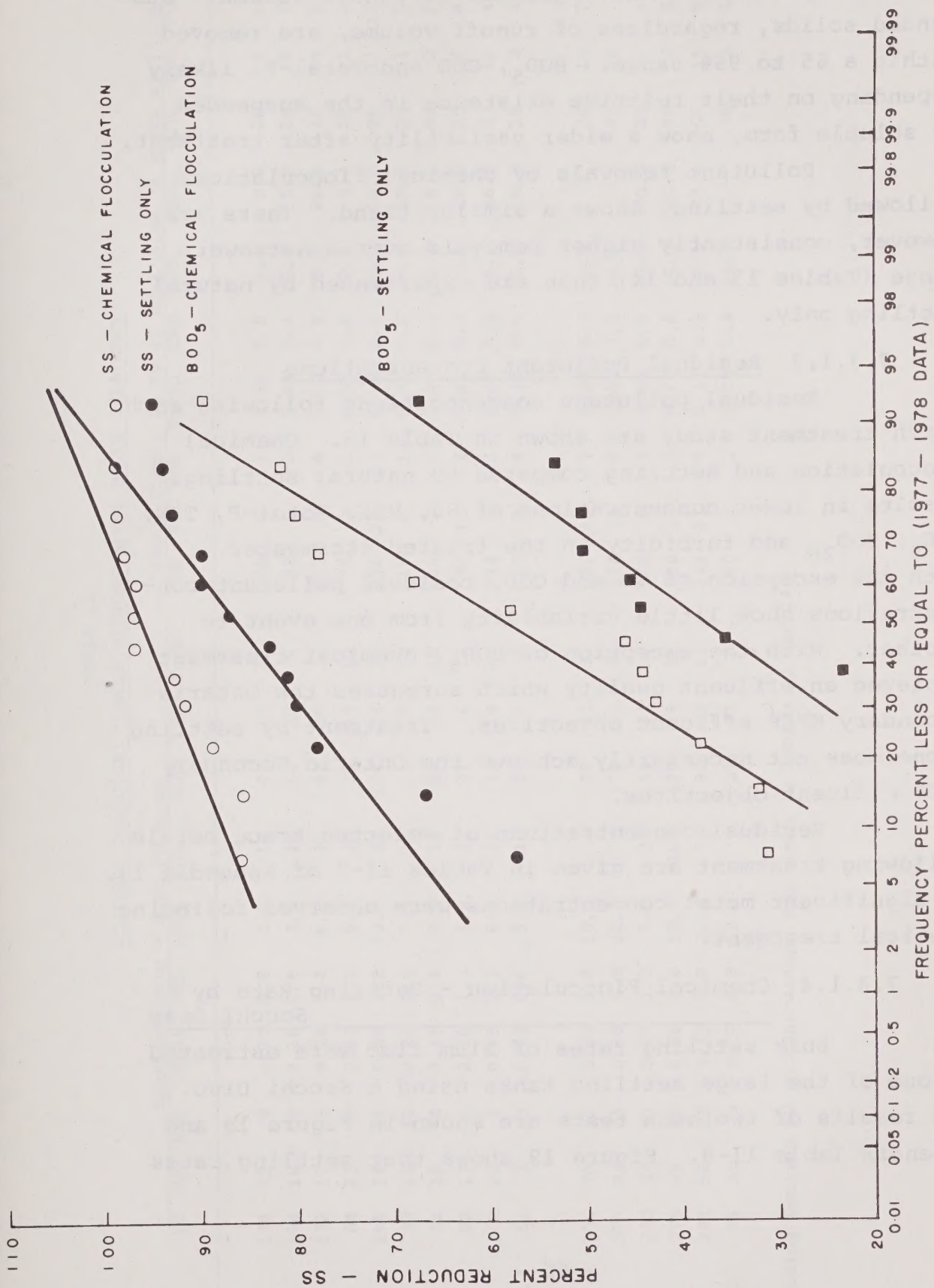


FIGURE 18 : PERCENT SS AND BOD₅ REDUCTION BY NATURAL AND CHEMICALLY ASSISTED SETTLING.

Treatment efficiency by natural settling appears to be independent of the magnitude of runoff volume. Suspended solids, regardless of runoff volume, are removed within a 65 to 95% range. BOD₅, COD and Total-P, likely depending on their relative existence in the suspended or soluble form, show a wider variability after treatment.

Pollutant removals by chemical flocculation followed by settling, shows a similar trend. There are, however, consistently higher removals over a narrower range (Tables 13 and 14) than are experienced by natural settling only.

7.3.1.3 Residual Pollutant Concentrations

Residual pollutant concentrations following each batch treatment study are shown in Table 15. Chemical flocculation and settling compared to natural settling, results in lower concentrations of SS, VSS, Total-P, TKN, BOD₅, BOD₂₀ and turbidity in the treated stormwater. With the exception of TS and COD, residual pollutant concentrations show little variability from one event to another. With the exception of BOD₅, chemical treatment achieved an effluent quality which surpasses the Ontario Secondary WPCP effluent objectives. Treatment by settling alone does not necessarily achieve the Ontario Secondary WPCP effluent objectives.

Residual concentrations of selected trace metals following treatment are given in Tables 11-7 of Appendix 11. No significant metal concentrations were observed following chemical treatment.

7.3.1.4 Chemical Flocculation - Settling Rate by Secchi Disc

Bulk settling rates of alum floc were estimated in one of the large settling tanks using a Secchi Disc. The results of two such tests are shown in Figure 19 and Appendix Table 11-8. Figure 19 shows that settling rates

TABLE 15

RESIDUAL POLLUTANT CONCENTRATIONS AFTER BATCH TREATMENT

Storm No.	Settling Only - 9 to 50 hours										Chem. Floc., 20 to 40 mg/L Alum, 2 hours settling									
	TS	SS	VSS	Total P	TKN	BOD ₅	BOD ₂₀	COD	TOC	Turb.	TS	SS	VSS	Total P	TKN	BOD ₅	BOD ₂₀	COD	TOC	Turb.
(1977)																				
21	174	22	9	0.20	0.8	3.0	14	43	17	12	140	3	1	0.20	0.8	1.6	9.0	26	6	1.5
22	104	18	7	0.18	0.8	3.5	14	14	10	9	92	5	2	0.04	0.4	0.8	5.5	26	5	1.6
23	132	17	8	0.26	1.4	6.0	35	41	16	7	122	8	4	0.10	0.8	5.0	22.0	33	14	2.6
24	84	21	6	0.22	1.2	6.5	20	36	14	10	70	3	1	0.02	0.8	2.0	5.0	20	11	2.5
26	190	24	14	0.32	2.2	20.0	55	104	24	13	236	28	13	0.32	2.0	20.0	53.0	104	27	16.0
27	83	20	15	0.25	1.5	7.0	37	39	15	14	116	6	1	0.06	0.6	4.0	19.0	20	11	4.0
31	34	19	6	0.16	0.4	2.0	11	20	4	10	44	2	1	0.04	0.2	0.4	4.5	44	3	0.8
33	92	17	8	2.00	1.5	1.8	21	31	8	12	90	12	4	0.04	0.4	1.2	10.0	25	4	4.5
Mean	112	20	9	0.45	1.2	6.2	26	41	14	11	114	8	3	0.10	0.8	4.4	16.0	37	10	4.2
Std. Dev.	51	3	3	0.63	0.6	5.9	15	27	6	2	58	9	4	0.10	0.6	6.5	16.3	28	8	4.9
(1978)																				
36	276	70	22	0.40	1.4	10.0	-	67	23	32	232	18	7	0.10	0.8	9.0	-	28	13	7.3
37	374	93	37	0.60	3.0	22.0	-	130	60	32	274	12	8	0.15	1.5	14.0	-	85	25	-
38	200	33	17	0.20	1.2	7.5	34	52	12	17	160	6	3	0.04	0.6	10.0	25.0	22	11	4.5
43	275	35	25	0.50	1.8	50.0	106	120	28	15	230	15	10	0.14	0.6	40.0	65.0	90	27	8.1
Mean	281	58	25	0.43	1.9	22.0	70	92	31	24	249	13	7	0.11	0.9	18.3	45.0	56	19	6.6
Std. Dev.	71	29	9	0.17	0.8	19.0	-	39	21	9	90	5	3	0.05	0.4	14.7	-	36	8	1.9

Corresponding Remixed SW Concentrations are given in Tables 13 and 14

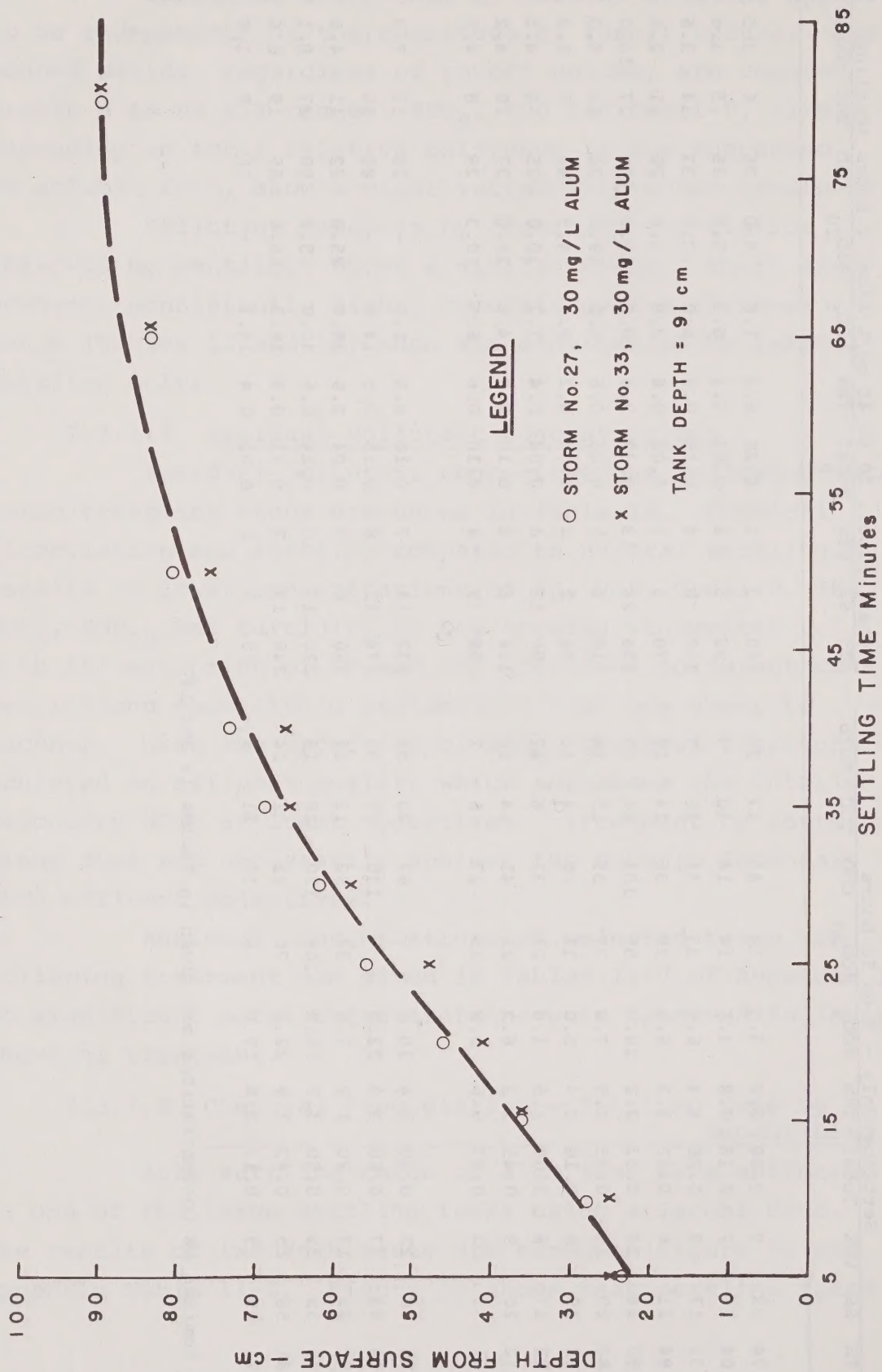


FIGURE 19 : CHEMICAL FLOCCULATION SETTLING RATE BY SECCHI DISC

varied little between the two storm events. An examination of Figure 19 indicates that the bulk settling rates for alum floc are in the order of 2 cm/min (.79 inches/minute) for the first 30 minutes. After 30 minutes, further settling of the floc had virtually ceased.

Estimated upflow rate, based on a bulk settling rate of 2 cm/min (.79 inches/minute) is $29 \text{ m}^3/\text{d.m}^2$ (590 gpd/ft²).

No sludge analysis was done following batch treatment studies due to insignificant quantities of sludge remaining at the tank bottom.

7.3.2 Stormwater Disinfection Studies

7.3.2.1 General Discussion

Disinfection of stormwater was achieved by treatment with sodium hypochlorite (NaOCl).

Stormwater disinfection was initiated at the bench-scale level using a jar tester to establish NaOCl dosages on samples from a wide range of storm events. The NaOCl dosage which consistently achieved satisfactory disinfection, was then used for pilot-scale, on-site treatment studies. Indicator bacteria used to evaluate disinfection studies were normally total and fecal coliforms and occasionally fecal streptococci. Disinfection was considered satisfactory if the proposed MOE WPCP microbiological effluent objective (2500/100 ml total coliform and 200/100 ml fecal coliform) was achieved. Indicator bacterial reduction by natural settling and chemical flocculation was also observed in the bench and pilot-scale treatment studies. Each sample was further investigated for possible bacterial regrowths for up to 48 hours following either disinfection or settling.

Total and fecal coliform concentrations (GM) in the raw and/or remixed stormwater were in the order of 7.5×10^5 and 9.0×10^3 counts/100 ml respectively, or well above proposed MOE objectives.

7.3.2.2 Bench-Scale Disinfection Studies

Disinfection testing with NaOCl was undertaken in the range of 5 to 15 mg/L total available chlorine. It was attempted to develop a typical average dosage which would, in most cases, reduce indicator bacteria to below MOE objectives. It was felt that a chlorine residual of 1.0 mg/L following 30 minutes contact time would, on the average, achieve MOE objectives. Typically, a dosage of 5 mg/L as total available chlorine produced satisfactory disinfection for the range of stormwater quality encountered.

For a typical 5.0 mg/L chlorine dosage, residual chlorine following the 30 minute contact time with and without chemical flocculation was in the order of 0.9 to 4.1 mg/L and 0.5 to 2.8 mg/L, respectively. The variation in chlorine demand is due to changes in the settled stormwater quality. Both the initial pollutant concentrations in the stormwater and the type of treatment (natural or chemically assisted) affect the quality and hence the demand. Variation in demand is not readily predictable. Accordingly, to achieve satisfactory disinfection, unless a bench-scale test is practical or residual monitoring is used, stormwater may have to be occasionally overdosed.

Residual indicator bacterial concentrations following bench-scale disinfection studies are shown in bar chart form in Figure 20 and 21 for runoff from a typical storm event. Detailed results of bench-scale disinfection are given in Table 11-9 of Appendix 11.

The indicated times (0, 24 and 48 hr) in the bar charts represent the elapsed time following completion of the respective treatment.

Settling only, for all practical purposes, achieved no reduction of the indicator bacteria measured nor was any regrowth observed. Chemical flocculation with 50 mg/L alum produced moderate bacterial removals. Additional minimal reductions were observed as samples

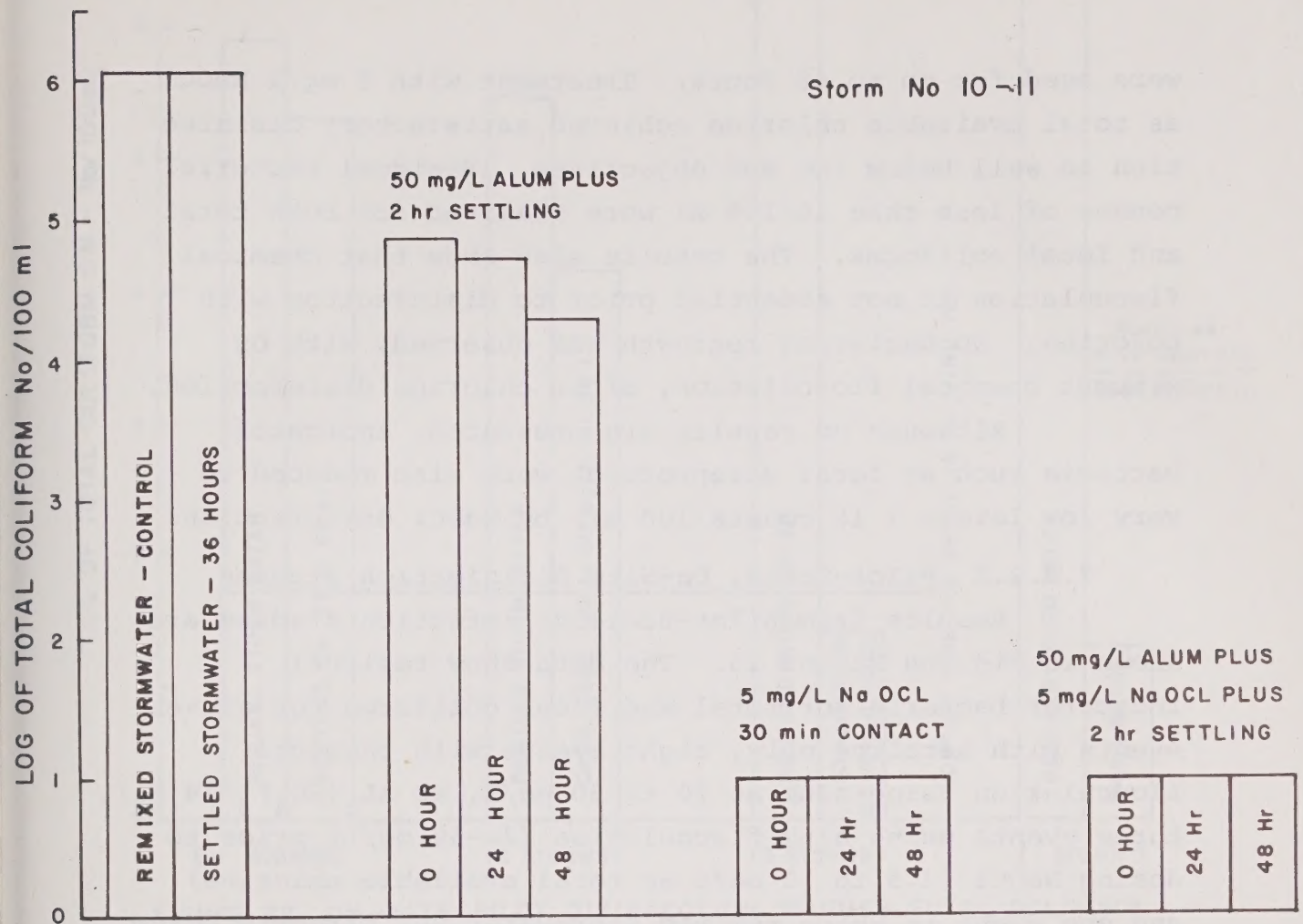


FIGURE 20 : TOTAL COLIFORM CONCENTRATIONS, BENCH SCALE DISINFECTION.

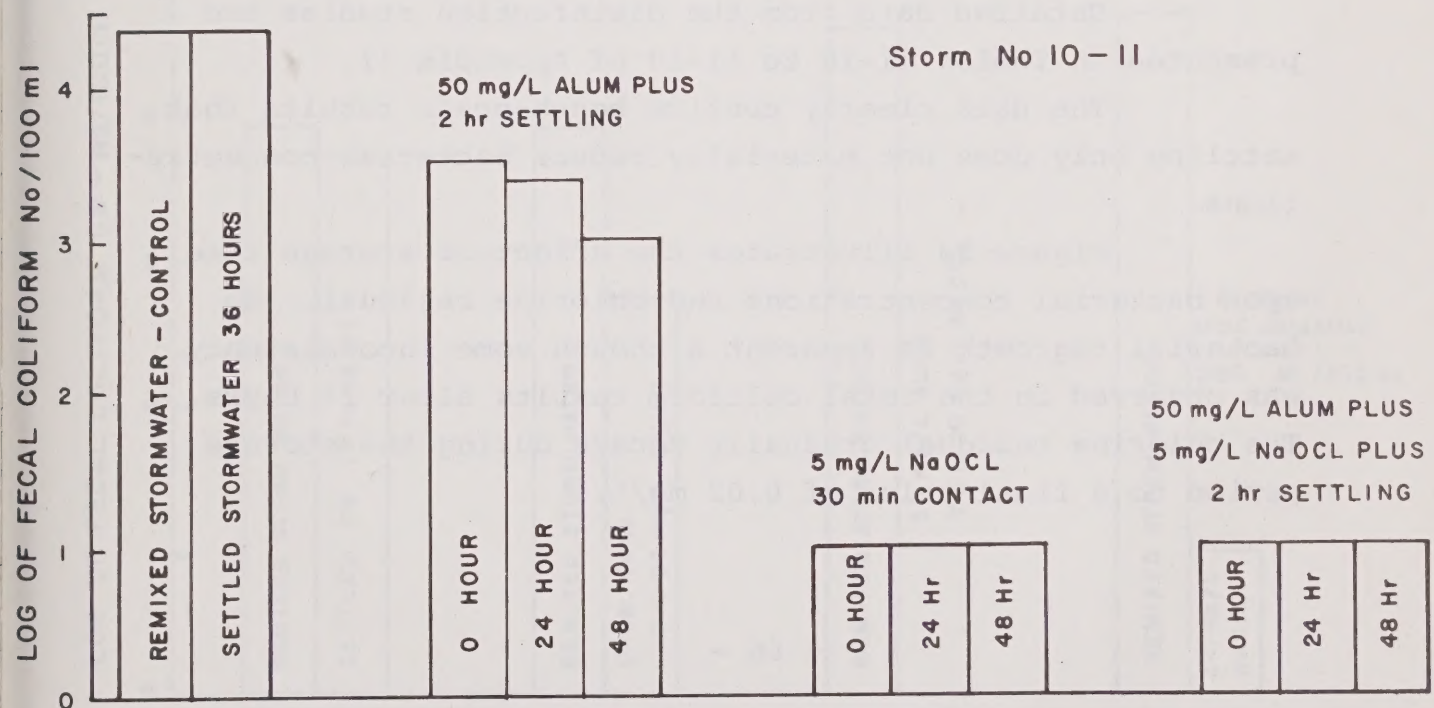


FIGURE 21 : FECAL COLIFORM CONCENTRATIONS, BENCH SCALE DISINFECTION.

were aged for up to 48 hours. Treatment with 5 mg/l NaOCl as total available chlorine achieved satisfactory disinfection to well below the MOE objectives. Residual bacterial counts of less than 10/100 ml were observed for both total and fecal coliforms. The results also show that chemical flocculation is not essential prior to disinfection with chlorine. No bacterial regrowth was observed, with or without chemical flocculation, after chlorine disinfection.

Although no results are presented, indicator bacteria such as fecal streptococci were also reduced to very low levels (10 counts/100 ml) by NaOCl disinfection.

7.3.2.3 Pilot-Scale, On-Site Disinfection Studies

Results from pilot-scale disinfection studies are shown in Figures 22 and 23. The data show residual indicator bacteria for total and fecal coliforms for eleven events with settling only, eight events with chemical flocculation using alum at 20 to 50 mg/L, as $AL_2(SO_4)_3 \cdot 14 H_2O$, three events using alum flocculation (20-50 mg/L) prior to dosing NaOCl (2.5 to 10 mg/L as total available chlorine) and one event in which remixed stormwater was directly dosed with 5.0 mg/L chlorine (NaOCl). Contact time for NaOCl was 30 minutes for the above illustrations.

Detailed data from the disinfection studies are presented in Tables 11-10 to 11-13 of Appendix 11.

The data clearly confirm bench-scale results that settling only does not materially reduce bacterial concentrations.

Figure 24 illustrates the effect of storage time upon bacterial concentrations and chlorine residual. No bacterial regrowth is apparent although some inconsistency was observed in the total coliform results after 24 hours. The chlorine residual gradually decays during the storage period to a final value of 0.02 mg/L.

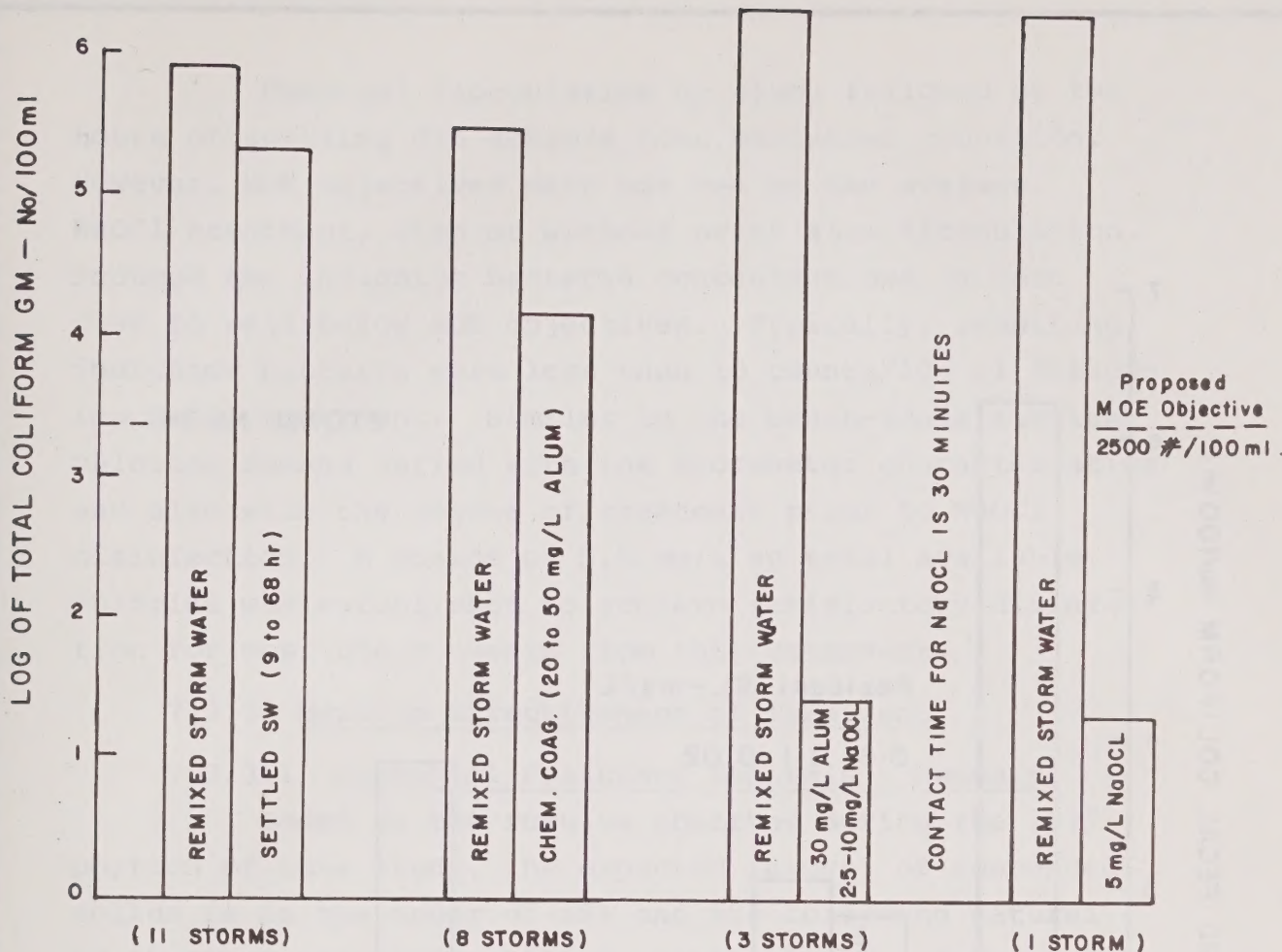


FIGURE 22 : ON-SITE PILOT DISINFECTION STUDIES. TOTAL COLIFORM CONCENTRATION.

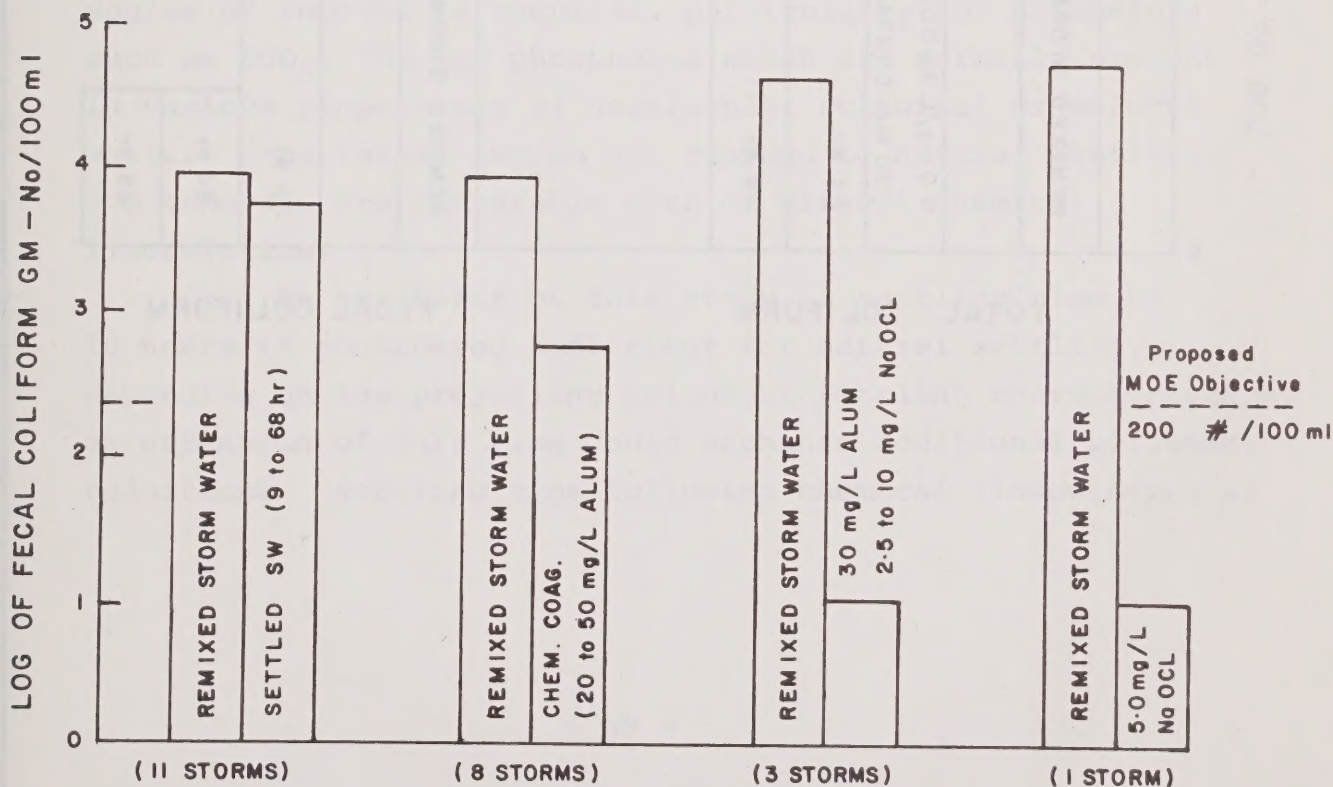


FIGURE 23 : ON-SITE PILOT DISINFECTION STUDIES. FECAL COLIFORM CONCENTRATION.

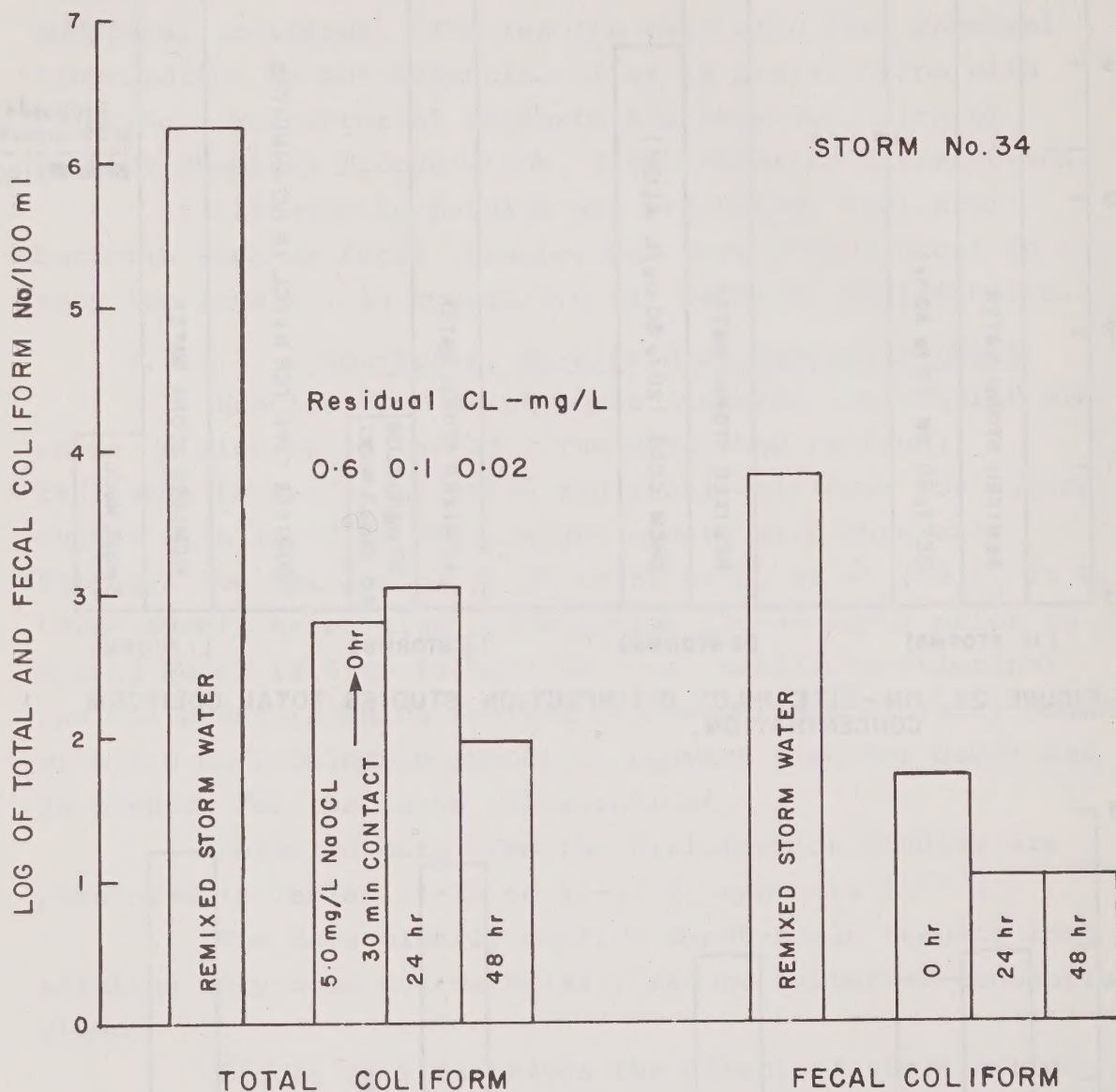


FIGURE 24 : ON SITE PILOT DISINFECTION STUDIES.

Chemical flocculation by alum, followed by two hours of settling did achieve some bacterial reduction. However, MOE objectives were not met on the average. NaOCl treatment, with or without prior alum flocculation, reduced the indicator bacteria concentrations in each case to well below MOE objectives. Typically, remaining indicator bacteria were less than 10 counts/100 ml following NaOCl treatment. Similar to the bench-scale studies, chlorine demand varied with the stormwater characteristics and also with the degree of treatment prior to NaOCl disinfection. A dosage of 5.0 mg/L as total available chlorine was established to achieve satisfactory disinfection for most storm events from this catchment.

7.3.3 Maximum Effectiveness of Treatment

7.3.3.1 Potential Pollutant Removals - Summary

Based on the results observed during the 1977 portion of this study, the expected removal of suspended solids is in the order of 88% and 95% following natural or chemical assisted settling, respectively. Suspended matter responds well to natural settling. Chemical flocculation may be essential if a consistently high degree of removal is required, particularly for parameters such as BOD₅, TKN and phosphorus which are normally present in various proportions of settleable, colloidal or soluble matter. The latter two do not respond to natural settling. COD removals are comparable with or without chemical flocculation.

On the basis of this study, a settling time of 10 hours is considered sufficient for natural settling. Depending on the prevailing pollutant settling characteristics, an extension of this time could enhance additional pollutant reductions. Settling time following chemical flocculation is

substantially shorter, a minimum of two hours under ideal conditions, but somewhat longer settling times may be required under full-scale operations. In addition, overall pollutant removals would be reduced since real or full-scale impoundment would not necessarily contain all storms or runoff for quiescent settling. Optimum chemical dosage of alum is established at 20 to 30 mg/L. Sodium hypochlorite, at a dosage of 5.0 mg/L as available chlorine, attained total fecal coliform reductions to below MOE objectives. Chemical dosages may be site specific.

7.3.3.2 Pollutant Mass Discharges With and Without Treatment

Pollutant mass discharges from the Barrington catchment area to the receiving stream are shown in Table 16 on the basis of:

- a) no treatment,
- b) potential discharge after settling only, and
- c) potential discharge after chemically assisted settling.

Potential percentage pollutant mass removals, as shown in Table 16, by settling only and chemically assisted settling, are based on the average pollutant removals according to pilot treatment studies.

Pollutant mass discharged from the thirteen 1977 storm events corresponds to 75% of the total runoff volume from 28 rainstorms during the 1977 study period. Mass pollutant discharge from five minor storm events during the 1978 study period is presented in Table 16 as the combined total mass only.

Overall pollutant mass loads of the observed events for untreated and treated stormwater are illustrated for SS, COD and BOD₅ in Figure 25. The substantial reduction, particularly of SS which represents the most abundant pollutant in stormwater, is apparent.

TABLE 16

POLLUTANT MASS DISCHARGE WITH AND WITHOUT TREATMENT (kg/ha)
(Based on Net Area of 17.4 ha)

Storm No.	No Treatment				Settling Only				Chem. Coag./Settling			
	SS	BOD ₅	COD	Total P	SS	BOD ₅	COD	Total P	SS	BOD ₅	COD	Total P
(1977)												
7	23.1	0.7	14.7	0.09	2.7	0.42	6.4	0.05	1.2	0.21	5.6	0.03
11	114.1	9.7	88.3	-	13.7	6.13	38.0	-	5.7	3.09	33.5	-
14	3.0	0.1	1.8	-	0.4	0.08	0.8	-	0.1	0.04	0.7	-
17	2.7	0.1	2.1	-	0.4	0.08	0.9	-	0.1	0.04	0.8	-
18	5.4	0.3	13.3	-	0.7	0.16	5.7	-	0.3	0.08	5.1	-
21	1.7	0.07	2.0	-	0.3	0.04	0.8	-	0.1	0.03	0.8	-
22	2.9	0.3	1.7	0.01	0.4	0.16	0.8	0.01	0.1	0.08	0.7	0.01
24	41.8	0.7	14.4	-	5.0	0.42	6.1	-	2.1	0.21	5.5	-
25	87.8	0.5	20.1	-	10.6	0.34	8.6	-	4.4	0.17	7.4	-
28	1.3	0.03	-	-	0.1	0.01	-	-	0.1	0.01	-	-
31	24.1	0.5	15.9	0.05	2.9	0.34	6.8	0.03	1.2	0.17	6.0	0.01
33	2.7	0.3	2.2	0.01	0.4	0.17	0.9	0.01	0.1	0.08	0.8	0.01
34	5.0	0.4	1.7	0.01	0.7	0.25	0.7	0.01	0.3	0.10	0.7	0.01
Total-1977	315.8	13.5	178.8	0.18	37.8	8.6	77.0	0.09	15.8	4.3	67.9	0.04
Total-1978	19.2	2.1	14.0	0.09	5.2	1.7	7.0	0.05	1.3	1.3	4.0	0.01

Removals in this table are based on average treatment results from Tables 16 and 17 and applied to all monitored storm events.

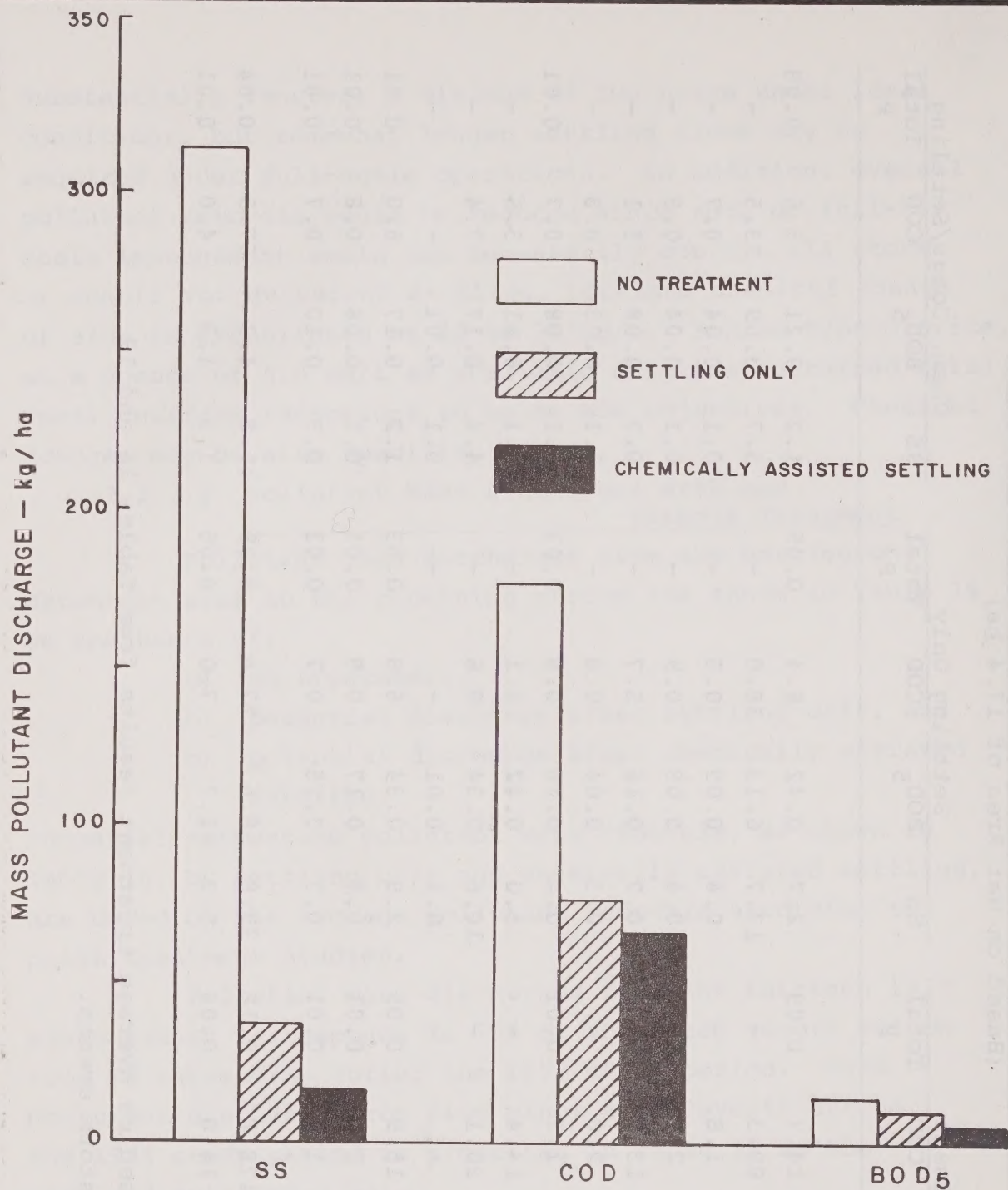
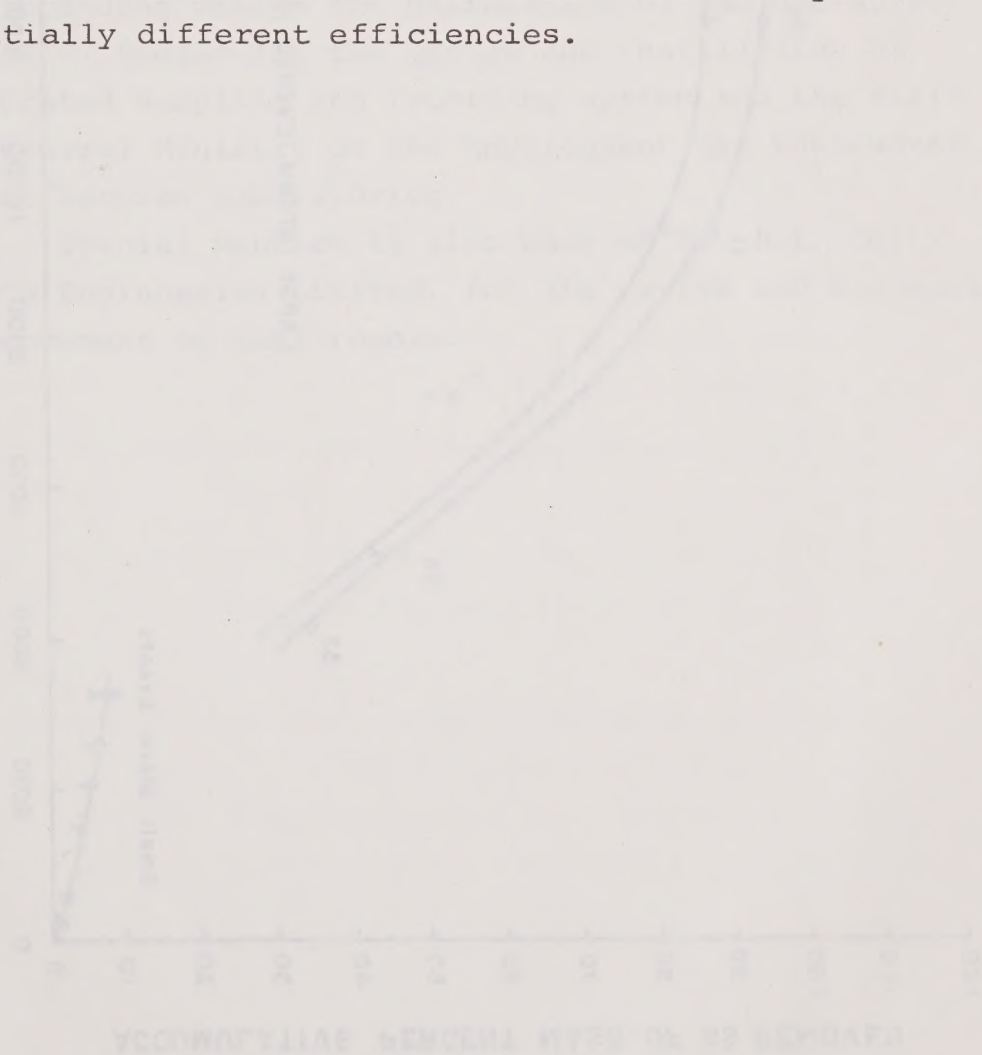


FIGURE 25 : MASS POLLUTANT DISCHARGES FOR 13 STORM EVENTS WITH AND WITHOUT TREATMENT. 1977 PERIOD .

The results indicate that settling alone, with the exception of bacterial reductions, may provide adequate treatment for stormwater. Chemically assisted settling may, however, be of significance if settling time is critical, thus reducing the required area requirements and capital costs of settling facilities.

Figure 26 illustrates potential accumulative percent suspended solids mass removal versus accumulative stored runoff volume. Potential reduction of treatment effectiveness due to sequential storm events is not considered. Data for this figure are based on monitored events during the 1977 study period. The attainable suspended solids mass removal by natural and chemically assisted settling is shown. For suspended solids, the difference in the two treatment methods does not yield substantially different efficiencies.



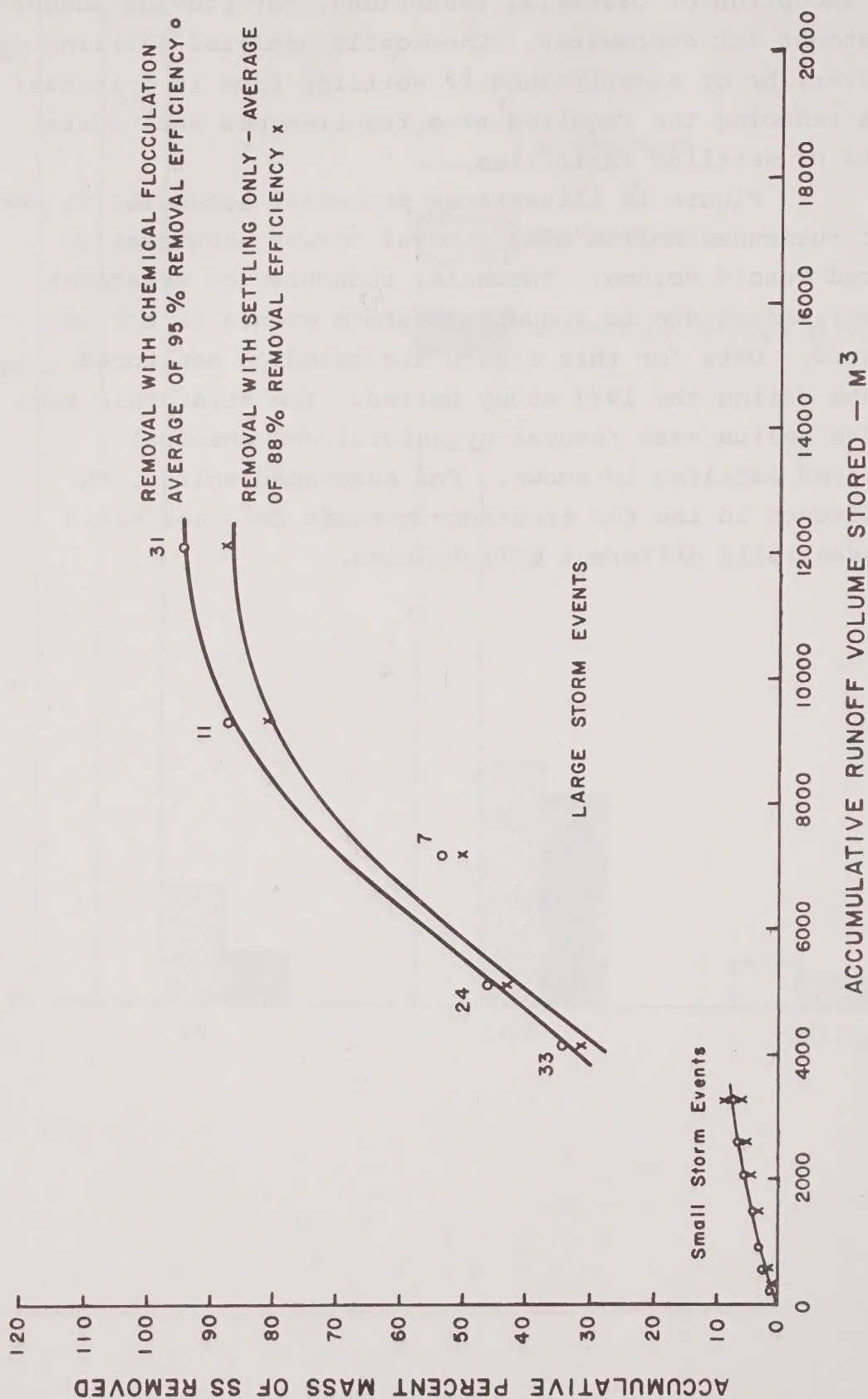


FIGURE 26 : ACCUMULATIVE STORED RUNOFF VOLUME Vs. ACCUMULATIVE PERCENT SS MASS REMOVAL.

ACKNOWLEDGEMENTS

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Special mention is also made of Mr. R.L. Smith of Simcoe Engineering Limited, for the review and suggestions for improvement of this report.

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APPENDIX 1

DESCRIPTION OF INSTRUMENTATION, MEASURING DEVICES, SAMPLE COLLECTION AND TREATMENT PROCEDURES

APPENDIX 1

DESCRIPTION OF INSTRUMENTATION, MEASURING DEVICES, SAMPLE COLLECTION AND TREATMENT PROCEDURES

1-1 GENERAL

This appendix deals with the physical description of the facilities used for data collection as well as testing procedures.

1-2 FLOW MEASUREMENTS

1-2-1 Primary Element

The primary flow measuring element had to be capable of measuring a large range of flows and, as a result, it was decided to utilize a dual range element in order to maintain accuracies. During a previous study, flow measurement at the Barrington site was achieved by means of a suitably instrumented vertical slot. An inspection of the slot installation and a review of reported flow measurement results yielded the following observations:

1. The majority of reported flowrate results occurred in a range of values below the calibrated range of the primary element.
2. The physical installation of the slot was poor as the slot plates were not axially aligned.

As a result, the Barrington flow measurement structure was redesigned in an attempt to both improve measurement resolution at low discharge and overall primary element range.

The primary element at Barrington is located in a 243.8 cm (96") diameter paved corrugated tunnel. A hand trowelled concrete paving reduces the tunnel diameter to 198.1 cm (78"). The paving extends to within 7.6 cm (3") of the tunnel mid-point. Average tunnel slope is 0.5%.

A compound slot weir was selected as the primary element best suited to the requirements of the Barrington site geometry and desired flow measurement range 42.5 - 1699 L/s (1.5 - 60 cfs). Slot and site geometry are presented in Figure 1-1.

A 1:7.8 scale model of the weir was constructed and installed in a 25.4 cm (10") diameter test pipeline in the laboratory of the Hydraulics Research Division, CCIW.

Calibration of the weir occurred in a period from January 10 to February 25, 1977. Thirty-five valid data points relating head to discharge were obtained for the model. The prototype head-discharge relationship was calculated on the basis of the identity of the Froude numbers in the model and in the prototype. Experimental and calculated results are indicated in Table 1-1. Model/prototype rating curves are presented in Figures 1-2, 1-3 and 1-4, respectively. A prototype discharge range of 47.86 to 2562.69 L/s (1.69 to 90.5 cfs) was obtained for head values ranging from 7.83 to 142.65 cm (0.257 to 4.68 ft).

Weir head is measured along the pipeline longitudinal axis 0.5 diameters upstream of the weir. In the prototype installation, this would represent a distance of 99 cm (3.25 ft) upstream of the weir. Relative discharge elevations of the bubbler tubes for the low and high range flow monitoring systems were at 73.4 mm and 600 mm, respectively, above the storm sewer invert.

1-2-2 Flow Measurement Instrumentation

In order to measure the head of water immediately upstream of the weir, a "bubbler type" measurement system was chosen.

TABLE 1-1

COMPOUND SLOT CALIBRATION DATA

Run No.	Qm c/s	hm ft	Qp cfs	hp ft	Qp L/s	hp cm
76	.013	.046	2.209	.359	62.55	10.94
67,68,20	.015	.056	2.549	.437	72.18	13.32
71,78	.016	.057	2.718	.445	76.97	13.56
57,58,69	.017	.069	2.888	.588	81.78	16.40
75	.018	.072	3.058	.562	86.59	17.13
73	.021	.082	3.568	.640	101.04	15.51
74	.025	.102	4.248	.796	120.29	24.26
6	.032	.147	5.437	1.147	153.56	34.96
26	.046	.171	7.815	1.334	221.30	40.66
7	.060	.206	10.194	1.607	288.66	48.98
19	.063	.210	10.704	1.638	303.11	49.23
23	.074	.223	12.573	1.739	356.03	53.01
18	.086	.249	14.611	1.942	413.74	59.19
22	.089	.246	15.121	1.919	428.18	58.49
27	.096	.259	16.310	2.020	461.85	61.57
1	.100	.282	16.990	2.200	481.11	67.06
25	.110	.282	18.689	2.200	529.22	67.06
9	.125	.315	21.238	2.547	601.40	74.89
17	.129	.327	21.917	2.551	620.62	77.76
59	.136	.312	23.106	2.434	654.29	74.19
2	.138	.328	23.446	2.558	663.92	77.97
56	.150	.328	25.485	2.558	721.66	77.97
5	.158	.371	26.844	2.894	760.14	88.21
24	.174	.364	29.563	2.839	837.14	86.53
4	.200	.407	33.980	3.175	962.21	96.77
55	.213	.413	36.189	3.221	1024.76	98.17
49	.249	.443	42.305	3.455	1197.95	105.31
3	.252	.443	42.815	3.455	1212.39	105.31
50	.270	.456	45.873	3.557	1298.99	108.42
51	.302	.469	51.310	3.658	1452.95	111.50
52	.340	.489	57.766	3.814	1635.76	116.25
47	.387	.518	65.751	3.030	1861.87	123.14
10	.410	.551	69.659	4.298	1972.53	131.00
54	.451	.538	76.625	4.196	2169.79	127.89
11	.920	.744	165.310	5.803	4426.23	176.88

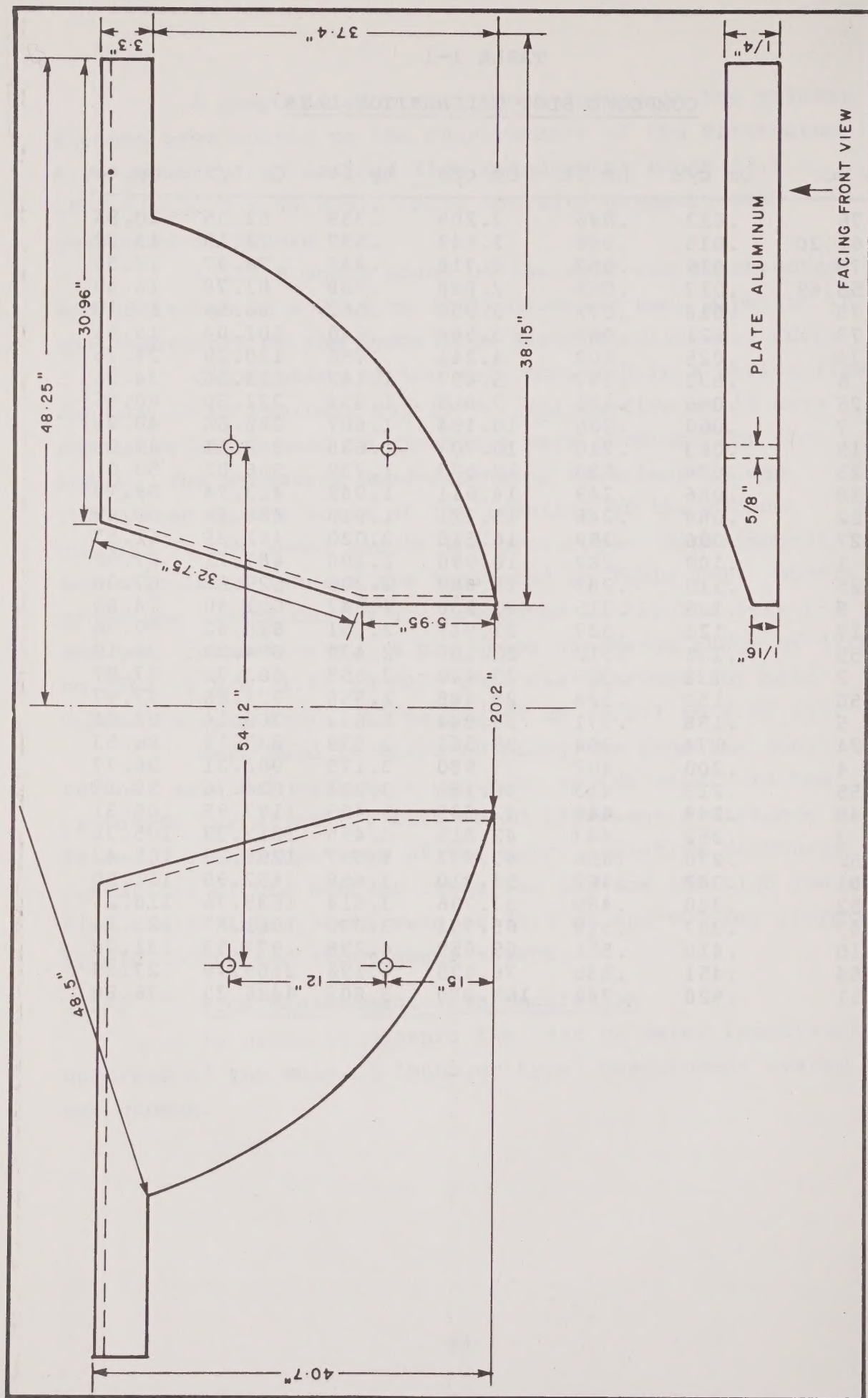


FIGURE I-1: BARRINGTON COMPOUND WEIR

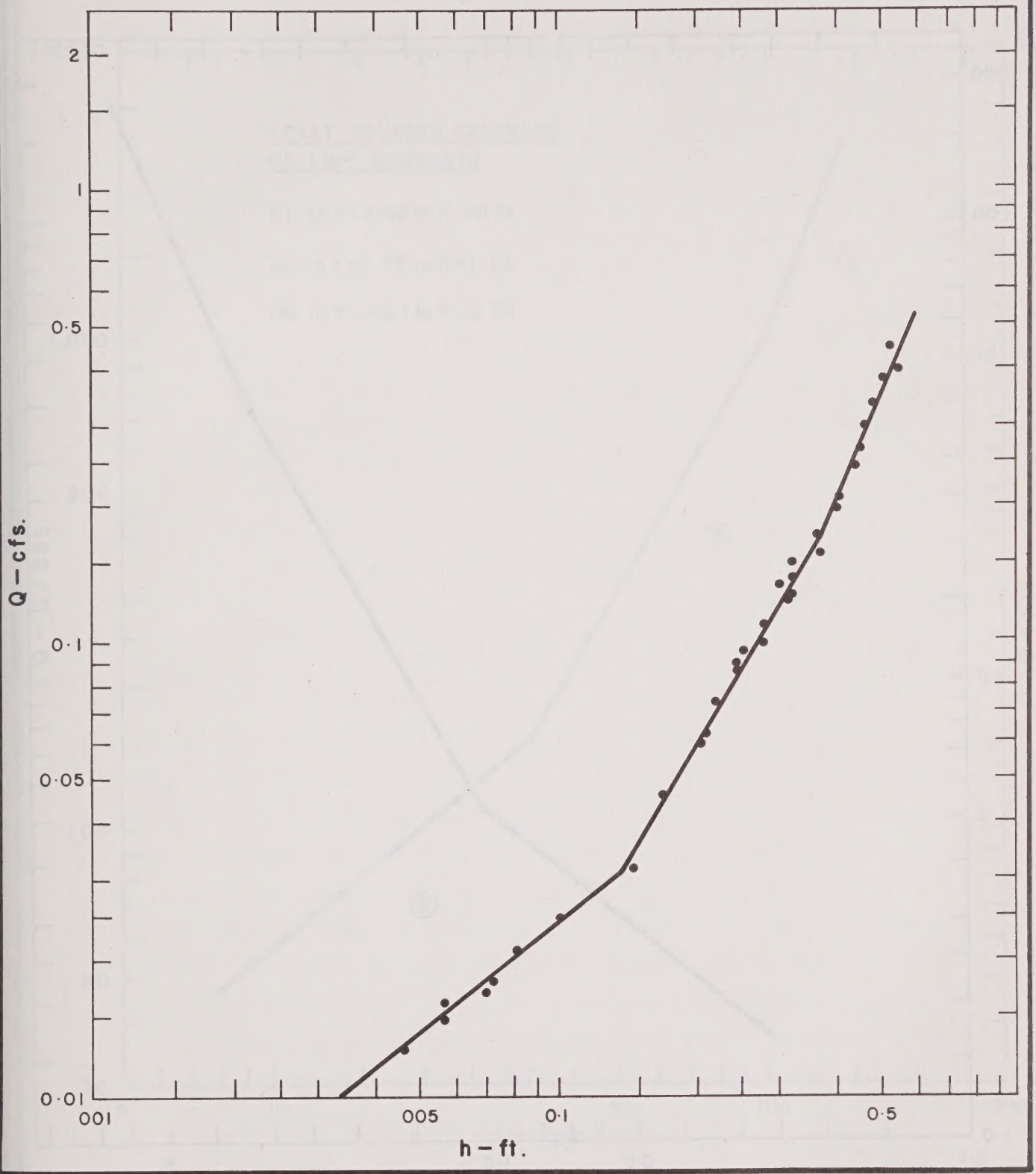


FIGURE I-2 : BARRINGTON MODEL WEIR CALIBRATION

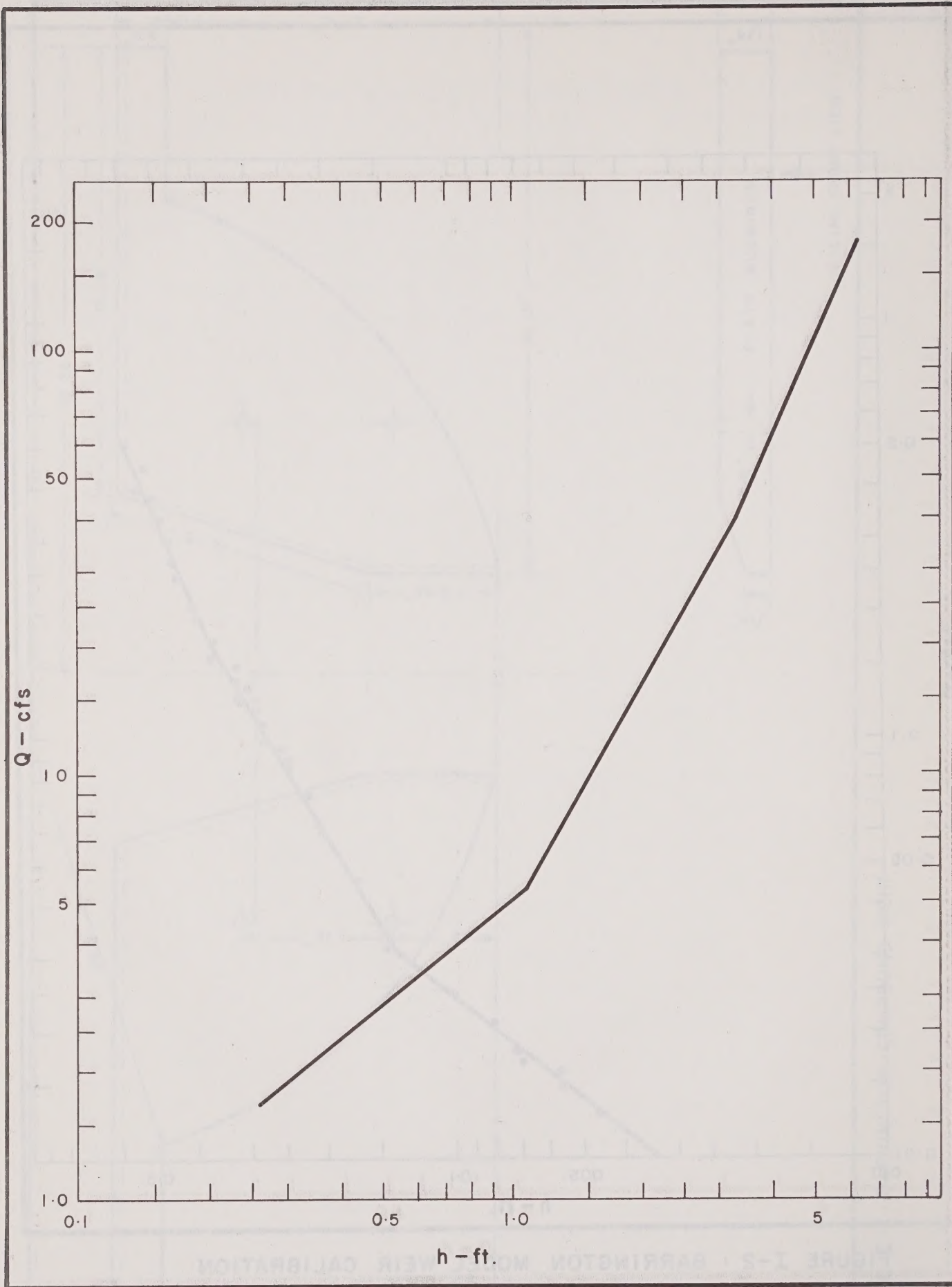


FIGURE I-3 : BARRINGTON WEIR PROTOTYPE CALIBRATION

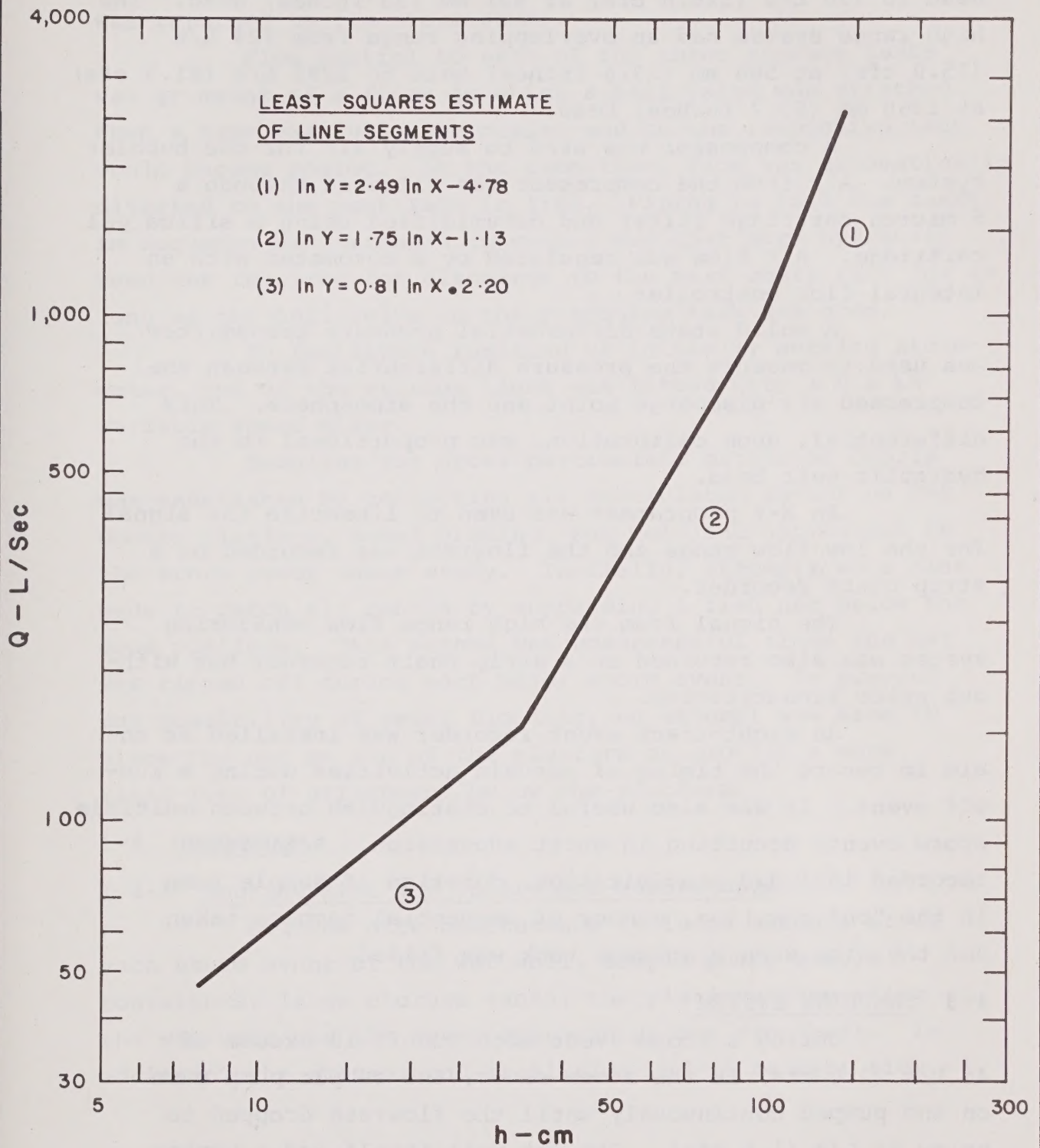


FIGURE I-4 : BARRINGTON WEIR PROTOTYPE CALIBRATION

Two sets of instruments, each covering a different flow range were employed. The low range system was scaled to measure flows from 45 L/s (1.6 cfs) at 73.4 mm (2.89 inches) head to 750 L/s (126.6 cfs) at 831 mm (33 inches) head. The high range system had an overlapping range from 424 L/s (15.0 cfs) at 500 mm (23.6 inches) head to 2292 L/s (81.5 cfs) at 1350 mm (53.2 inches) head.

A compressor was used to supply air for the bubbler system. Air from the compressor was filtered through a 5 micron cartridge filter and dehumidified using a silica gel cartridge. Air flow was regulated by a rotometer with an integral flow controller.

A solid state differential pressure transmitter was used to measure the pressure differential between the compressed air discharge point and the atmosphere. This differential, upon calibration, was proportional to the hydraulic weir head.

An X-Y programmer was used to linearize the signal for the low flow range and the flowrate was recorded on a strip chart recorder.

The signal from the high range flow monitoring system was also recorded on a strip chart recorder but without prior linearization.

An eight-track event recorder was installed as an aid to record the timing of certain activities during a runoff event. It was also useful to distinguish between multiple storm events occurring in short succession. Activities recorded included precipitation, duration of sample pump in the "on" position, number of sequential samples taken and the time when a storage tank was filled.

1-3 SAMPLING SYSTEM

During a storm event with runoff in excess of 45 L/s (1.6 cfs) in the storm sewer, the sample pump came on and pumped continuously until the flowrate dropped to below 45 L/s (1.6 cfs). The wet well itself had a number of openings near the bottom for quick drainage after the flow had stopped.

If the storm event was of sufficient duration and all of the storage tanks had been sequentially filled, i.e. without overflow from one tank to another, pumped stormwater was returned to the storm sewer.

Flow control to each of the three storage tanks was by means of a float to which a ball valve was attached. When a tank was full, the outlet end to the respective tank would become sealed. At the same time, flow was automatically diverted to the next tank in line. Piping to fill the tanks in sequence was arranged in such a way that more hydraulic head was required for discharge to the next empty tank for as long as the ball valve to the preceding tank was open.

To facilitate remixing of initially settled stormwater, one of the storage tanks was fitted with a 0.6 kW variable speed mixer.

Sampling for gross particulate matter or debris was undertaken by collecting all accumulated matter on the wooden platform, steel grating, wet well and approaches in the storm sewer under study. Initially, attempts were also made to catch all debris by suspending a fish net below the wood platform. This method was unsuccessful since the net was ripped off during each major storm event. To prevent any possibility of sewer flooding, no attempt was made to place the net on top of the platform or provide a more rigid form of attachment below the platform.

1-4 OPERATION

1-4-1 Routine Site and Instrument Maintenance

Routine site maintenance included cleanup after each storm event of the wet well, sample pump, sample containers, large storage tanks, the platform supporting the wet well and the sewer approaching the dropshaft. In addition, the aboveground facilities had to be kept tidy.

After each storm event or site visit, all instrumentation and sampling devices were checked for satisfactory operation. Flow recording charts were taken after each storm event and replaced as needed. The raingauge recorder required chart changing on a daily basis or at least after each storm event. The area around the weir and bubbler outlet points were also checked after each event. Desiccant for instrument air had to be changed every 2 to 3 days.

Although one person was capable of maintaining and looking after the site, two persons, for safety reasons, were generally on hand when below ground work was done.

1-4-2 Operating Experience

Startup of the flow monitoring and sampling systems proceeded without major difficulties. However, within two weeks the two-channel flow monitoring recorder malfunctioned and would no longer produce reliable data. Eventually, it was replaced by another unit. The latter, although not providing as good data resolutions, performed satisfactorily.

A further problem which became apparent within the first few storm events, was the ponding of stormwater in the sewer. Ponding was a result of a foot high retaining wall (sill) located at the point where the storm sewer discharged to the main dropshaft. As a consequence, a backwater was created to a point about 30 m upstream of the weir. This ponding effect destroyed the accuracy of the flow measurement system. In addition, large quantities of sand and heavy material were deposited in this area. The sill was subsequently removed with the Borough's permission.

Visual observations during some storms revealed that during high storm sewer flowrates (>750 L/s), the two other storm sewers discharged into the sampling area of the storm sewer under study. Under these conditions, the dropshaft flooded well above the level of the sampling wet well and consequently, considerable intermixing occurred. During

low to moderate storm events, no intermixing of the sewers occurred. Since the catchment characteristics of the other two drainage areas are similar to the one under study, intermixing should not have significantly affected stormwater quality.

The automated sampling system operated satisfactorily. The only problem observed was some corrosion in an electric junction box located in the dropshaft. This led to a power failure for the submersible pump. Occasionally, the sample pump intake screen was completely plugged requiring disassembly for proper cleaning.

A problem with respect to sample analysis was caused by the extremely fast settling rate of sand in the stormwater. In fact, sand settled faster than the time it took to take aliquots from the well-mixed sample bottle. This made the accurate determination of TS, SS and VSS impossible. To overcome the problem, appropriate aliquots were taken on-site while keeping the sample well mixed using a suitable stirring device.

1-5 TREATMENT PROCEDURES

Jar testing was performed in preparation for on-site pilot-scale flocculation and disinfection studies. Methodology of these studies was as follows:

Jar Testing - For this test, a 6 unit Phipps and Bird variable speed stirrer was used. Sample volume depended on the required analysis and was either 1 or 2 liters. Chemicals used in conjunction with jar testing were alum and FeCl_3 . These chemicals were prepared as 1% solutions for ease of dosing. One ml of this solution when added to 1 L of sample corresponded to a dosage of 10 mg/L.

The actual jar testing sequence was as follows:

1. Fill 1 L or 2 L beakers as required.
2. Insert stirrers.
3. Adjust stirring speed to 100 rpm (rapid mix).
4. Add chemicals to each beaker in succession.

5. Maintain rapid mix for 2 minutes after chemical addition.
6. Reduce speed to 30 rpm and maintain for 15 minutes.
7. Stop stirrer and remove stirring paddle from beakers.
8. Let settle for 30 minutes.
9. Comment on relative settling rates and clarity of treated samples as well as floating solids or floc remaining in suspension.
10. Decant any floating materials and carefully, without disturbing the settled sludge, take samples for routine tests as shown in Figure 7 of Section 6.

Disinfection - Bench-scale disinfection studies were done by using Javex-5 (NaOCl) with a nominal concentration of 5.25% available chlorine. Javex-5 was diluted to about 1% available chlorine for ease of dosing. Disinfection was investigated on "remixed" and naturally or chemically clarified stormwater samples. The tests utilized the previously described jar tester with the following sequence:

1. Check chlorine solution strength each time prior to use.
2. Fill 1 L or 2L beakers as needed and insert stirrers.
3. Adjust stirring speed to 100 rpm.
4. Dose disinfectant and maintain agitation for 3 minutes.
5. Reduce speed to 30 rpm and maintain for 30 minutes.
6. Fill 6 oz bacti bottles containing sodium thiosulphate.
7. Determine residual chlorine by the amperometric method immediately upon completion of test.

Occasionally, samples which had been disinfected with either Javex-5 or chemical flocculants were stored and tested for bacterial regrowth after 24 and 48 hours. Storage was under ambient conditions in the laboratory with the sample bottles unsealed. Bacteriological testing was done as outlined in Figure 7.

APPENDIX 11

SUMMARY OF DATA COLLECTED

APPENDIX 11

SUMMARY OF DATA COLLECTED

Hydrologic data for individual storm events is presented in Table 11-1.

Stormwater runoff quality is shown in Tables 11-2 to 11-6.

Trace metal concentrations, with and without treatment, are shown in Table 11-7. Table 11-8 shows details of Secchi Disc settling tests.

Results of stormwater disinfection studies at the bench and pilot-scale levels, are shown in Tables 11-9 to 11-13. Figure 11-1 illustrates a BOD curve for stormwater.

TABLE 11-1
RAINFALL/RUNOFF EVENT CHARACTERISTICS

Date	Storm No.	Rainfall cm	Duration hours	Average Intensity cm/hr	Runoff cm	Runoff Coefficient (Runoff-cm) (Rainfall-cm)	Peak Flowrate L/sec	Total Volume of Runoff m ³	Dry Days Since Last Storm
(1977)									
May 31	1	1.78	4.0	0.45	-	-	-	-	30
June 2	2	0.41	1.0	0.41	-	-	-	-	2
June 17	3	0.91	1.7	0.55	-	-	-	-	15
June 18	4	1.80	2.0	0.90	0.71	0.40	600	1256	1
June 25	5	1.32	1.0	1.32	-	-	-	-	7
June 29	6	3.30	2.1	1.57	-	-	-	-	4
July 6	7	3.86	3.3	1.17	1.17	0.30	2005	2038	7
July 7	8	0.81	2.0	0.40	0.14	0.18	110	259	1
July 15	9	1.02	0.4	2.55	0.40	0.39	1025	710	1
July 29	10	0.41	0.3	1.37	0.07	0.16	100	120	8
July 31	11	2.39	0.3	7.97	1.31	0.55	2290	2161	14
Aug. 5	12	0.41	0.5	0.82	0.03	0.07	80	38	2
Aug. 5	13	1.57	0.9	1.74	0.47	0.30	1150	813	4
Aug. 6	14	1.22	1.2	1.02	0.34	0.27	500	595	0.75
Aug. 6	15	0.25	0.7	0.36	0.03	0.10	110	51	0.33
Aug. 8	16	0.56	1.7	0.33	0.08	0.14	110	144	2
Aug. 10	17	1.52	3.0	0.51	0.29	0.18	490	504	0.5
Aug. 10	18	0.71	0.5	1.42	0.31	0.44	640	542	2
Aug. 10	19	0.25	0.25	1.00	0.09	0.37	180	149	0.6
Aug. 14	20	0.81	0.8	1.01	0.21	0.26	560	360	0.2
Aug. 16	21	0.51	0.8	0.64	0.13	0.26	110	221	3.5
Aug. 21	22	3.05	4.0	0.76	0.21	0.07	300	370	2
Aug. 27	23	0.51	0.20	2.55	0.09	0.18	270	154	5
Sept. 1	24	1.52	0.17	8.94	0.55	0.37	1035	944	6
Sept. 1	25	1.17	0.33	3.54	0.51	0.43	1800	883	5
Sept. 9	26	0.56	0.17	3.29	0.07	0.12	180	115	0.2
Sept. 13	27	1.01	15.00	0.07	-	-	-	-	9
Sept. 16	28	0.15	0.17	0.88	0.02	0.13	80	34	4
Sept. 16	29	1.02	4.00	0.26	0.09	0.09	120	156	3
Sept. 18	30	0.59	0.33	1.79	0.09	0.16	200	168	0.2
Sept. 24	31	5.69	10.00	0.57	1.62	0.28	520	2808	2
Sept. 26	32	1.73	3.00	0.58	0.46	0.26	120	792	6

Table 11-1 - cont'd

Date	Storm No.	Rainfall cm	Duration hours	Average Intensity cm/hr	Runoff cm	Runoff Coefficient (Runoff-cm) (Rainfall-cm)	Peak Flowrate L/sec	Total Volume of Runoff m ³	Dry Days Since Last Storm
Oct. 1	33	1.67	4.00	0.42	0.38	0.22	110	662	5
Oct. 8	34	1.72	5.5	0.31	0.12	0.18	100	354	7
Oct. 9	35	0.91	2.5	0.37	0.03	0.03	55	44	0.5
(1978)									
April 6	36	1.78	6.0	0.29	-	-	100	-	-
May 8	37	1.32	4.0	0.33	0.16	0.12	120	278	2
May 13-14	38	1.48	8.0	0.19	0.05	0.04	60	86	5
May 14	39	0.91	2.5	0.36	0.10	0.12	130	182	0.1
May 20	40	0.61	1.7	0.36	0.07	0.01	60	115	6
June 12	41	0.36	0.08	4.50	0.04	0.01	80	58	23
June 12	42	0.46	0.66	0.70	0.07	0.14	120	115	0.16
July 3	43	0.86	4.0	0.22	0.03	0.03	45	50	20

TABLE 11-2
SOLIDS CONCENTRATION

Storm No.	Total Solids - mg/l			Susp. Solids - mg/L			Vol. Susp. Solids - mg/L			No. of Samples
	Avg.	Std. Dev.	Range	Avg.	Std. Dev.	Range	Avg.	Std. Dev.	Range	
1	420	126	225- 670	148	92	50- 354	55	26	22-110	11*
3	341	178	202- 599	142	100	54- 277	50	36	24- 92	4*
4	98	10	87- 109	16	7	8- 25	-	-	-	5*
5	1387	1289	158-3460	56	66	18- 172	21	17	12- 50	5*
7	1208	665	905-2620	139	98	29- 332	39	25	6- 86	7*
11	1029	599	631-1750	598	516	157-1195	185	148	55-365	5
13	470	61	415- 525	162	87	94- 282	39	22	22- 71	4
14	270	59	210- 330	71	22	45- 91	15	6	10- 22	5
17	225	36	178- 264	89	22	58- 105	23	8	12- 32	4
18	262	95	180- 395	131	77	69- 241	27	17	14- 52	4
21	190	57	140- 315	115	67	65- 250	46	26	25- 90	7
22	251	59	161- 311	117	40	75- 180	43	14	30- 60	5
25	1533	352	1330-1940	940	209	795-1180	235	91	132-304	3
26	5355	2203	2335-6980	1798	336	1480-2165	147	41	90-195	5
29	264	184	190- 680	115	182	15- 525	-	-	-	8
31	292	107	180- 515	233	125	100- 470	48	22	25-105	12*
33	104	28	66- 140	50	21	21- 88	22	7	12- 29	12*
34	185	66	66- 100	132	54	40- 250	37	14	21- 68	12*
37	480	350	148-1430	241	247	45-1090	97	95	22-424	22
39	298	94	180- 400	186	82	80- 270	-	-	-	4
40	-	-	-	144	5	140- 151	-	-	-	5
41	1135	-	900-1370	835	-	640-1030	358	-	210-505	2
42	432	-	365- 490	257	-	175- 340	133	-	94-190	3
43	288	-	225- 390	112	-	90- 135	67	-	60- 75	3

*pairs of consecutive samples combined

TABLE 11-3

ORGANIC CONCENTRATIONS

Storm No.	BOD5 - mg/L			COD - mg/L			TOC - mg/L		
	Avg.	Std.	Range	Avg.	Std.	Range	Avg.	Std.	Range
1	42	8	22-50	195	51	139-283	51	11	37-62
3	41	30	23-85	159	96	87-300	60	21	44-91
4	5	1	3-6	31	5	23-36	12	1	10-13
5	5	3	2-7	51	32	13-95	19	6	14-27
7	5	2	4-8	96	69	31-210	8	4	3-14
11	61	45	26-130	498	397	126-1035	118	80	52-244
13	5	2	3-8	85	63	48-178	35	27	10-61
14	3	1	2-4	41	15	28-58	13	8	6-25
17	8	2	6-10	75	19	52-98	22	8	12-30
18	8	3	7-12	270	336	46-769	17	3	14-20
21	6	2	5-10	79	80	37-258	22	9	12-37
22	8	3	6-13	56	42	32-130	13	5	21-25
25	15	1	14-16	171	201	92-400	31	9	5-18
26	11	5	8-19	354	195	172-506	39	24	13-73
29	3	2	2-6	-	-	-	-	-	-
31	6	2	4-10	120	134	36-531	16	7	9-37
33	4	1	3-7	41	15	25-69	9	5	7-18
34	9	3	7-16	36	23	20-80	17	6	12-35
37	15	9	6-30	172	129	55-530	22	9	11-47
39	7	1	6-9	134	28	97-160	-	-	-
40	115	33	70-150	274	42	230-330	-	-	-
41	170	-	90-250	625	-	610-640	-	-	-
42	39	-	32-50	290	-	160-500	-	-	-
43	50	-	-	-	-	-	-	-	-

TABLE 11-4

NUTRIENT CONCENTRATIONS

Storm No.	Total-P - mg/L			Soluble-P - mg/L			NH ₃ -N - mg/L		
	Avg.	Std. Dev.	Range	Avg.	Std. Dev.	Range	Avg.	Std. Dev.	Range
1	-	-	-	-	-	-	0.71	0.03	0.7-0.8
3	0.80	0.44	0.45-1.4	0.06	0.33	0.02-0.10	0.60	0.47	0.3-1.3
4	0.15	0.03	0.12-0.2	0.02	0.009	0.02-0.02	0.20	0.17	0.1-0.5
5	0.57	0.25	0.34-0.8	0.06	0.01	0.04-0.08	0.10	0.02	0.1-0.4
7	0.55	0.49	0.04-1.4	0.05	0.02	0.40-0.10	0.23	0.07	0.2-0.4
11	-	-	-	0.04	0.12	0.02-0.60	-	-	-
13	-	-	-	0.06	0.02	0.04-0.08	-	-	-
14	-	-	-	0.07	0.02	0.04-0.08	-	-	-
17	-	-	-	-	-	-	-	-	-
18	-	-	-	0.07	0.05	0.04-0.14	-	-	-
21	-	-	-	0.02	-	0.02-0.02	-	-	-
22	0.53	0.35	0.24-1.1	0.06	0.05	0.04-0.16	0.22	0.19	0.1-0.6
25	-	-	-	0.11	0.03	0.08-0.14	-	-	-
26	-	-	-	0.09	0.06	0.06-0.20	-	-	-
29	-	-	-	-	-	-	-	-	-
31	0.55	0.18	0.35-0.9	0.05	0.01	0.04-0.08	0.1	-	0.1-0.2
33	0.31	0.10	0.15-0.5	0.05	0.01	0.04-0.08	0.1	-	0.1-0.1
34	0.35	0.27	0.18-1.2	0.09	0.02	0.06-0.10	0.1	-	0.1-0.1
37	0.85	0.62	0.4-3.0	0.07	0.04	0.04-0.2	<0.1	-	0.1-0.1
39	0.71	0.23	0.42-0.9	0.03	0.01	0.02-0.04	<0.1	-	-
40	0.77	0.12	0.60-0.9	0.02	-	-	<0.1	-	-
41	3.45	-	2.2-4.7	0.07	-	0.02-0.12	0.5	-	0.4-0.6
42	1.43	-	1.2-1.8	0.15	-	0.06-0.12	0.1	-	-
43	0.83	-	0.68-1.0	<0.02	-	-	<0.1	-	-

Table 11-4 - cont'd

Storm No.	NO ₃ -N - mg/l			TKN - mg/L		
	Avg.	Std. Dev.	Range	Avg.	Std. Dev.	Range
1	<0.1	-	<0.1	5.2	1.01	3.5 - 7.5
3	0.46	0.33	0.10-0.9	3.9	2.3	2.0 - 7.2
4	0.44	0.21	0.12-0.2	0.86	0.19	0.7 - 1.2
5	-	-	-	1.72	1.10	0.8 - 3.6
7	0.39	0.14	0.2 -0.6	2.1	2.32	0.6 - 4.6
11	-	-	-	-	-	-
13	-	-	-	-	-	-
14	-	-	-	-	-	-
17	-	-	-	-	-	-
18	-	-	-	-	-	-
21	-	-	-	-	-	-
22	0.55	0.19	0.40-0.9	2.03	2.20	0.80- 6.4
25	-	-	-	-	-	-
26	-	-	-	-	-	-
29	-	-	-	-	-	-
31	0.50	0.40	0.10-1.4	1.30	0.66	0.50- 2.0
33	0.64	0.46	1.7 -0.3	1.38	0.43	1.0 - 2.0
34	0.6	0.28	0.3 -1.0	1.32	0.97	0.6 - 4.2
37	0.6	0.08	0.5 -0.7	3.0	2.0	1.4 - 9.0
39	0.1	0.05	-	2.7	0.7	1.8 - 3.4
40	0.1	-	-	4.5	0.7	3.8 - 5.5
41	0.1	-	-	19.5	-	13.0 -26.0
42	0.25	-	0.1 -0.2	5.4	-	4.2 - 6.4
43	<0.01	-	-	3.1	-	2.6 - 3.6

TABLE 11-5

OTHER PHYSICAL POLLUTANT PARAMETERS

Storm No.	pH		Alkalinity - mg/L		Conductivity - ohms/cm		Turbidity*					
	Avg.	Std. Dev.	Range	Avg.	Std. Dev.	Range	Avg.	Std. Dev.	Range			
1	7	0.08	6.7-6.9	70	18	38-102	401	61	265-480	46	16	20-71
3	7	0.05	7 -7	50	27	35- 90	251	96	190-395	36	15	24-57
4	6.6	0.10	6.5-6.7	17	4	12- 22	75	12	60- 90	7	4	4-13
5	7.2	0.25	7.0-7.6	29	6	23- 35	126	33	85-165	12	7	6-23
7	7.5	0.08	7.5-7.6	26	6	20- 39	75	14	62-106	20	8	10-35
22	7.2	0.16	7.1-7.5	28	5	23- 38	92	17	81-124	16	7	9-29
31	7.5	0.15	7.3-7.6	57	9	-	95	36	50-170	20	3	15-25
33	7.4	0.25	6.6-7.6	28	5	23- 40	77	22	60-135	16	2	11-19
34	7.4	0.13	7.2-7.6	26	5	22- 42	97	22	71-150	14	2	11-18
37	7.5	0.11	7.2-7.6	-	-	-	-	-	-	46	19	23-92
39	7.3	0.05	7.2-7.3	-	-	-	-	-	-	32	5	26-38
40	6.0	0.2	5.8-6.3	-	-	-	-	-	-	24	2	22-27
41	6.9	-	6.7-7.0	-	-	-	-	-	-	69	-	48-90
42	7.1	-	7.0-7.2	-	-	-	-	-	-	44	-	42-47
43	6.9	-	-	-	-	-	-	-	-	22	-	21-25

TABLE 11-6
BACTERIOLOGICAL CONCENTRATIONS (#/100 ml)

Storm No.	Time	Total Coliforms	Fecal Coliforms	Fecal Streptococci
3	x	1.4×10^6	2.2×10^4	7.1×10^4
3	xx	2.2×10^6	3.0×10^3	6.3×10^4
7	0	5.7×10^5	1.8×10^4	7.1×10^4
7	30	2.0×10^5	1.2×10^4	4.7×10^4
7	60	7.0×10^4	7.3×10^3	4.4×10^4
7	90	1.7×10^5	1.1×10^4	4.6×10^4
10	x	1.4×10^6	2.7×10^4	1.3×10^3
23	x	3.2×10^6	5.2×10^3	1.2×10^4

Time: Minutes since start of storm
 x: Sampled during early stage of runoff
 xx: Sampled during latter stage of runoff

TABLE 11-7
TRACE METAL CONCENTRATIONS IN REMIXED, SETTLED AND CHEMICALLY COAGULATED STORMWATER

Storm No.	Remixed SW conc. - mg/L			Settling Time (hours)	Settled SW Conc. - mg/L			Alum Dosage mg/L	Chemically Coagulated Stormwater Conc. - mg/L			
	Cu	Ni	Pb		Cu	Ni	Pb		Cu	Ni	Pb	Zn
21	0.04	0.02	0.32	12	0.05	0.07	0.14	0.09	0.02	0.02	0.03	0.04
22	0.05	0.06	0.76	12	0.03	0.02	0.08	0.06	-	-	-	-
22	0.05	0.06	0.76	34	0.01	0.02	0.07	0.04	0.02	0.02	0.03	0.04
23	0.05	0.04	0.73	45	0.03	0.01	0.12	0.05	0.02	0.02	0.04	0.02
24	0.07	0.03	0.67	18	0.02	0.01	0.11	0.10	0.02	0.02	0.03	0.04
26	0.12	0.06	1.00	50	0.17	0.17	0.19	0.14	0.04	0.02	0.20	0.20
27	0.04	0.02	0.29	11	0.04	0.02	0.18	0.10	0.02	0.01	0.04	0.04
28	0.04	0.02	0.77	1	0.04	0.02	0.63	0.28	-	-	-	-
31	0.04	0.02	0.30	9	0.01	0.02	0.05	0.05	-	-	-	-
31	0.04	0.02	0.30	34	0.03	0.02	0.06	0.05	0.01	0.02	0.03	0.02
32	-	-	-	48	0.01	0.02	0.04	0.02	0.01	0.02	0.03	0.02
33	0.02	0.02	0.46	42	0.01	0.02	0.14	0.09	0.01	0.02	0.04	0.07
34	0.04	0.02	0.52	68	0.02	0.02	0.18	0.12	-	-	-	-
Average	0.05	0.03	0.57	-	0.04	0.03	0.15	0.09	0.02	0.02	0.05	0.05
Std. Dev.	0.03	0.02	0.24	-	0.04	0.04	0.15	0.70	0.01	0.01	0.06	0.06
Minimum	0.02	0.02	0.29	-	0.01	0.01	0.05	0.02	0.01	0.01	0.03	0.02
Maximum	0.12	0.06	1.00	-	0.17	0.17	0.63	0.28	0.04	0.02	0.20	0.20

Settling Time After Coagulation - 2 hours

Table 11-7 - cont'd

Storm No.	Remixed SW Conc. - mg/L				Settling Time (hours)	Settled SW Conc. - mg/L				Alum Dosage (mg/L)	Chemically Coagulated Stormwater Conc. - mg/L			
	Cd	Cr	Mn	Fe		Cd	Cr	Mn	Fe		Cd	Cr	Mn	Fe
21	0.005	0.04	0.10	3.9	12	0.005	0.04	0.05	1.30	30	0.005	0.02	0.03	0.08
22	0.005	0.04	0.10	5.2	12	0.005	0.02	0.08	0.85	-	-	-	-	-
22	0.005	0.04	0.10	5.2	34	0.005	0.02	0.03	0.50	20	0.005	0.02	0.03	0.15
23	0.005	0.04	0.23	8.3	45	0.005	0.03	0.04	0.83	30	0.005	0.02	0.05	0.16
24	0.005	0.04	0.27	8.8	18	0.005	0.02	0.04	4.00	30	0.005	0.02	0.05	0.10
26	0.005	0.04	0.23	11.0	50	0.005	0.06	0.11	1.50	30	0.005	0.04	0.09	1.60
27	0.01	0.04	0.06	1.9	11	0.01	0.04	0.04	1.20	30	0.005	0.02	0.02	0.29
28	0.01	0.08	0.14	6.4	1	0.01	0.04	0.11	5.00	-	-	-	-	-
31	0.005	0.04	0.12	4.3	9	0.005	0.02	0.02	0.08	-	-	-	-	-
31	0.005	0.04	0.12	4.3	34	0.005	0.02	0.02	0.40	20	0.005	0.02	0.03	0.07
32	-	-	-	-	48	0.005	0.02	0.02	0.34	20	0.005	0.02	0.01	0.12
33	0.005	0.04	0.07	2.4	42	0.005	0.02	0.04	0.75	30	0.005	0.02	0.03	0.18
34	0.005	0.04	0.13	3.8	68	0.005	0.04	0.06	0.95	-	-	-	-	-
Average	0.006	0.04	0.14	5.46	-	0.006	0.03	0.05	1.42	-	0.005	0.02	0.04	0.31
Std. Dev.	0.002	0.01	0.07	2.71	-	0.002	0.02	0.03	1.42	-	-	0.01	0.02	0.49
Minimum	0.005	0.04	0.06	1.9	-	0.005	0.02	0.02	0.34	-	0.005	0.02	0.01	0.07
Maximum	0.01	0.08	0.27	11.0	-	0.01	0.06	0.11	5.00	-	0.005	0.04	0.09	1.60

TABLE 11-8

ON-SITE SETTLING TESTS - SECCHI DISC

Storm No. 27		Storm No. 33	
Remixed, Initially Settled 12 Hours Alum Dosage - 30 mg/L		Remixed, Initially Settled 42 Hours Alum Dosage - 30 mg/L	
Time - minutes	Depth - cm	Time - minutes	Depth - cm
5	23	5	25
10	28	10	25
15	36	15	36
20	46	20	41
25	56	25	48
30	61	30	58
35	69	35	66
40	74	40	66
50	81	50	76
65	84	65	84
80	91 (bottom)	80	91 (bottom)

TABLE 11-9

DISINFECTION OF STORMWATER - BENCH-SCALE STUDIES

Storm No.	Settling Time (hours)	NaOCl mg/L	Coagulant mg/L	Contact Time (min.)	Residual Chlorine mg/L	Hours Since Disinfection	Bacteriological Conc. - No./100 ml		
							Tot. Col.	Fec. Col.	Fec. Strep.
4	48	-	-	-	-	-	2.2×10^3	5.1×10^2	10
		5	-	15	2.2	0	10	10	10
		10	-	15	3.3	0	10	10	10
		15	-	15	6.2	0	10	10	10
		0	Alum-40	-	-	0	20	10	10
		0	Alum-60	-	-	0	10	10	10
5	48	-	-	-	-	-	8.3×10^3	1.29×10^3	30
		-	Alum-30	-	-	0	1.7×10^3	20	10
		-	Alum-30	-	-	24	80	10	10
		-	Alum-30	-	-	48	10	10	10
		-	FeCl ₃ -20	-	-	0	1.3×10^2	10	10
		-	FeCl ₃ -20	-	-	24	1.1×10^2	10	10
		-	FeCl ₃ -20	-	-	48	10	10	10
		5	-	30	0.9	0	10	10	10
		5	-	-	-	24	10	10	10
		5	-	-	-	48	10	10	10
		10	-	30	6.8	0	10	10	10
		10	-	-	-	24	10	10	10
7	0	10	-	-	-	48	10	10	10
		-	-	-	-	-	1.5×10^5	4.6×10^5	3.6×10^4
		5	-	30	1.6	0	100	10	10
		10	-	30	3.6	0	10	10	10
		15	-	30	5.2	0	10	10	10
		-	-	-	-	-	2.5×10^5	1.4×10^4	9.2×10^4
7	16	5	-	30	2.8	0	10	10	10
		10	-	30	6.7	0	10	10	10
		15	-	30	11.4	0	10	10	10
		-	-	-	-	-	10	10	10

All samples dechlorinated after indicated contact time

Table 11-9 - cont'd

Storm No.	Settling Time (hours)	NaOCl mg/L	Coagulant mg/L	Contact Time (min.)	Residual Chlorine mg/L	Hours Since Disinfection	Bacteriological Conc. - No/100 ml		
							Tot. Col.	Fec. Col.	Fec. Strep.
10-11	36	-	-	-	-	-	1.13x10 ⁶	2.5 x10 ⁴	3.0 x10 ³
		-	Alum-50	-	-	0	8.2 x10 ⁴	3.4 x10 ³	1.13x10 ³
		-	Alum-50	-	-	24	5.5 x10 ⁴	2.6 x10 ³	1.09x10 ³
		-	Alum-50	-	-	48	2.1 x10 ⁴	1.08x10 ³	1.6 x10 ²
		5	-	30	1.6	0	10	10	10
		5	-	-	-	24	10	10	10
		5	-	-	-	48	10	10	10
		10	-	30	2.1	0	10	10	10
		10	-	-	-	24	10	10	10
		10	-	-	-	48	10	10	10
		5	Alum-50	30	2.4	0	10	10	10
		5	Alum-50	-	-	24	10	10	10
		5	Alum-50	-	-	48	10	10	10
		10	Alum-50	30	4.3	0	20	10	10
13-14	48	10	Alum-50	-	-	24	10	10	10
		10	Alum-50	-	-	48	10	10	10
		-	-	-	-	-	8.9 x10 ³	6.9 x10 ²	2.4 x10 ³
		5	-	30	2.4	0	10	10	10
		10	-	30	5.3	0	10	10	10
21	12	15	-	30	11.5	0	10	10	10
		-	-	-	-	-	7.9 x10 ⁴	1.5 x10 ³	8.7 x10 ²
		5	-	30	2.8	0	10	10	10
		10	-	30	6.9	0	10	10	10
		15	-	30	9.8	0	10	10	10
		-	Alum-30	-	-	0	4.3 x10 ³	2.1 x10 ²	10
		5	Alum-30	30	4.1	0	10	10	10
		10	Alum-30	30	8.0	0	10	10	10
		15	Alum-30	30	12.4	0	10	10	10
		-	-	-	-	-	-	-	-

All samples dechlorinated after indicated contact time

Table 11-9 - cont'd

Storm No.	Settling Time (hours)	NaOCl mg/L	Coagulant mg/L	Contact Time (min.)	Residual Chlorine mg/L	Hours Since Disinfection	Bacteriological Conc. - No./100 ml		
							Tot. Col.	Fec. Col.	Fec. Strep.
22	34	-	-	-	-	-	8.3x10 ⁴	6.4x10 ³	8.5x10 ³
		5	-	30	2.8	0	10	10	10
		10	-	30	5.2	0	10	10	10
		15	-	30	8.4	0	10	10	10
		-	Alum-20	-	-	0	4.2x10 ³	6.7x10 ²	60
23	45	5	Alum-20	30	3.0	0	10	10	10
		10	Alum-20	30	6.4	0	10	10	10
		15	Alum-20	30	9.2	0	10	10	10
		-	-	-	-	-	8.1x10 ⁴	10	6.7x10 ²
		5	-	30	0.5	0	10	10	10
		10	-	30	1.4	0	10	10	10
		15	-	30	4.3	0	10	10	10
		-	Alum-30	-	-	0	1.6x10 ³	20	2.1x10 ²
		5	Alum-30	30	0.9	0	10	10	10
		10	Alum-30	30	2.4	0	10	10	10
		15	Alum-30	30	5.7	0	10	10	10

All samples dechlorinated after indicated contact time

TABLE 11-10

BACTERIOLOGICAL CONCENTRATIONS AND REMOVALS BY ON-SITE NATURAL SEDIMENTATION

Storm No.	Remixed SW - No/100 ml			Settled SW - No/100 ml			Settling Time (hours)
	Tot. Col.	Fec. Col.	Fec. Strep.	Tot. Col.	Fec. Col.	Fec. Strep.	
13-14	4.1 x10 ⁵	2.6 x10 ⁴	3.3 x10 ³	3.5 x10 ⁵	3.6 x10 ³	2.7 x10 ³	48
21	5.3 x10 ⁵	3.2 x10 ³	5.4 x10 ⁴	6.2 x10 ⁵	1.5 x10 ⁴	3.1 x10 ⁴	12
22	6.8 x10 ⁴	7.3 x10 ³	1.05x10 ⁴	1.0 x10 ⁴	1.03x10 ³	2.5 x10 ³	12
22	6.8 x10 ⁵	7.3 x10 ¹	1.05x10 ⁴	8.3 x10 ⁴	6.4 x10 ¹	8.5 x10 ³	34
23	1.6 x10 ⁴	3.0 x10 ³	9.9 x10 ³	8.1 x10 ⁴	1.0 x10 ³	6.7 x10 ³	45
24	1.5 x10 ⁷	1.5 x10 ⁵	1.5 x10 ⁴	1.5 x10 ⁷	1.5 x10 ⁵	1.5 x10 ³	18
26	1.7 x10 ⁵	8.7 x10 ⁴	1.5 x10 ⁴	1.18x10 ⁵	5.3 x10 ⁴	1.5 x10 ⁴	50
27	5.8 x10 ⁵	1.3 x10 ⁴	2.6 x10 ⁴	6.1 x10 ⁴	1.27x10 ⁴	4.1 x10 ⁴	11
31	1.06x10 ⁵	1.40x10 ⁴	2.2 x10 ⁴	9.9 x10 ⁴	2.3 x10 ⁴	6.5 x10 ⁴	9
31	1.06x10 ⁵	1.40x10 ⁴	2.2 x10 ⁴	9.2 x10 ⁶	2.0 x10 ⁴	2.8 x10 ³	34
34	1.68x10 ⁶	6.3 x10 ³	8.0 x10 ³	1.71x10 ⁶	6.4 x10 ³	7.3 x10 ³	68
G.M.	7.58x10 ⁵	8.9 x10 ³	1.41x10 ⁴	2.3 x10 ⁵	5.36x10 ³	1.28x10 ⁴	31
Std. Dev.	6.12 ⁴	11.50 ¹	3.43 ³	6.78 ⁴	13.80 ¹	3.24 ³	-
Minimum	6.8 x10 ⁷	3.0 x10 ⁵	1.5 x10 ⁴	1.5 x10 ⁷	1.0 x10 ⁵	1.5 x10 ⁴	-
Maximum	1.7 x10 ⁷	8.7 x10 ⁵	9.9 x10 ⁴	1.2 x10 ⁷	5.3 x10 ⁵	6.5 x10 ⁴	-

TABLE 11-11
BACTERIOLOGICAL CONCENTRATIONS AND REMOVALS BY ON-SITE CHEMICAL COAGULATION

Storm No.	Remixed SW - No/100 ml			Coagulant	Dosage mg/L	Chem. Treated SW - No/100 ml		
	Tot. Col.	Fec. Col.	Fec. Strep.			Tot. Col.	Fec. Col.	Fec. Strep.
10-11	8.9 x10 ⁶	1.1 x10 ⁵	5.6 x10 ⁴	Alum	50	1.7 x10 ⁵	3.9 x10 ³	4.6 x10 ³
12	4.9 x10 ⁵	1.5 x10 ⁴	2.5 x10 ⁴	FeCl ₃	40	1.03x10 ³	7.6 x10 ²	5.0 x10 ²
21	5.3 x10 ⁴	3.2 x10 ³	5.4 x10 ⁴	Alum	30	6.4 x10 ³	2.3 x10 ²	4.0 x10
22	6.8 x10 ⁵	7.3 x10	1.05x10 ⁴	Alum	20	4.2 x10 ³	6.7 x10 ²	6.0 x10 ²
23	1.6 x10 ⁴	3.0 x10 ³	9.9 x10 ³	Alum	30	1.6 x10 ⁴	2.0 x10 ³	2.1 x10 ²
24	1.5 x10 ⁵	1.5 x10 ⁴	1.5 x10 ⁴	Alum	30	1.83x10 ³	1.5 x10 ²	8.2 x10 ²
31	1.06x10 ⁵	1.4 x10 ⁴	2.2 x10	Alum	20	1.62x10 ⁴	1.4 x10 ²	6.3 x10 ²
32	1.39x10 ⁵	1.34x10 ⁴	-	Alum	20	7.3 x10	5.1 x10 ²	-
G.M.	2.99x10 ⁵	8.43x10 ³	2.2 x10 ⁴	-	-	1.41x10 ⁴	5.61x10 ²	3.46x10 ²
Std. Dev.	8.67	15.14	4.42	-	-	6.47	6.71	5.13
Minimum	1.5 x10 ⁶	3.0 x10 ⁵	1.5 x10 ⁴	-	-	1.6 x10 ⁵	2.0 x10 ³	4.0 x10 ³
Maximum	8.9 x10 ⁶	1.5 x10	5.6 x10	-	-	1.7 x10	7.6 x10	4.6 x10

TABLE 11-12
BACTERIOLOGICAL CONCENTRATIONS AND REMOVALS BY ON-SITE TREATMENT WITH ALUM/NaOCl

Storm No.	Raw SW Conc. - No/100 ml		Alum mg/L	NaOCl mg/L	Treated SW Conc. - No/100 ml	
	Tot. Col.	Fec. Col.			Tot. Col.	Fec. Col.
26	1.7 x10 ⁷	8.7 x10 ⁵	30	10	9.0 x10	1.0x10
27	5.8 x10 ⁵	1.3 x10 ⁴	30	10	1.0 x10	1.0x10
28	1.7 x10 ⁶	5.7 x10 ⁴	-	5	2.0 x10	1.0x10
33	6.2 x10 ⁵	7.0 x10 ³	30	2.5	2.0 x10	1.0x10
G.M.	1.8 x10 ⁶	4.61x10 ⁴	-	-	2.45x10	1.0x10

Contact time for chlorination - 30 minutes prior to sampling

TABLE 11-13
BACTERIOLOGICAL CONCENTRATIONS AND REMOVALS BY ON-SITE DISINFECTION WITH NaOCl
INCLUDING REGROWTH OF BACTERIA

Storm No.	Settling Time (hours)	NaOCl mg/L	Contact Time (min.)	Chlorine Residual mg/L	Bacteriological Conc. - No/100 ml			Hours Since Disinfection
					Tot. Col.	Fec. Col.	Fec. Strep.	
34	70	-	-	-	1.68×10^6	6.3×10^3	8.0×10^3	-
	-	5	30	0.6	6.3×10^2	50	60	0
	-	5	-	0.1	1.13×10^3	10	40	24
	-	5	-	0.02	90	10	20	48
31-32	24	5	-	3.3	100	10	10	2
	-	5	-	-	100	10	-	24
	-	5	-	-	10	10	-	48
	-	5	-	-	-	-	-	-

All samples dechlorinated at time of sampling.
Storm No. 31-32 - chlorine mixed into surface layer.
All sampling at 30 cm depth.
Zero hours since disinfection corresponds to end of 30 minute contact time.

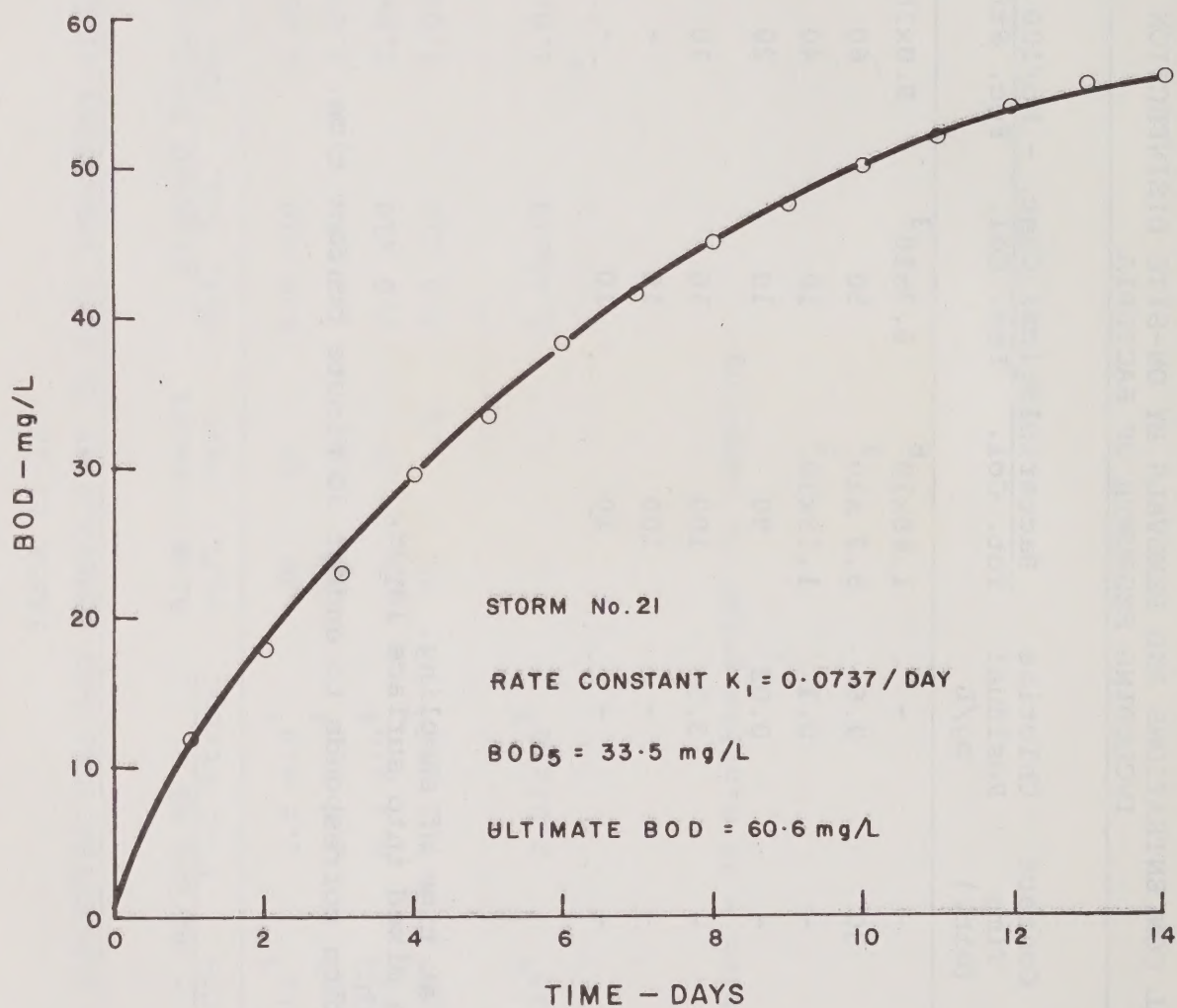


FIGURE II-1 BOD CURVE - BARRINGTON STORMWATER

CA20NEV 82R88

Ontario. MOE.

Research Report No.88

PHYSICAL-CHEMICAL TREATMENT AND DISINFECTION OF
STORMWATER. 1982.

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